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Economic Decision Guide Software (EDGe$) with Loss Amplification and Risk Aversion

Wildfire Urban Interface (WUI) Case Studies

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Abstract

This report demonstrates an example of loss amplification and risk aversion in benefit-cost analysis (BCA) for community resilience planning. The tool used is the NIST Economic Decision Guide Software (EDGe$) Online Tool, which assesses the economic feasibility of community resilience alternatives. Loss amplification arises from a catastrophe modeling method used to represent the increased costs associated with repair activity during a demand surge after a large catastrophe and could also be applied to mortality costs if the age of mortality is expected to skew younger. Risk aversion is a measure of a community's (or other entity's) preference to avoid uncertainty. Risk aversion parameters can be used to compute certainty equivalent payoffs from uncertain payoffs and specific levels of risk aversion. A fictitious case study of wildfire disaster planning of a wildland-urban interface (WUI) is employed to demonstrate these two model enhancements (i.e., loss amplification and risk aversion) and their effects on the economic indicator outputs from EDGe$. The presented case study evaluates a binary development choice related to the resilience of a large presidential library from the perspective of two neighboring communities.

Keywords

Benefit-cost analysis; community resilience; economic analysis; economic decision tool; loss amplification; demand surge; risk attitude; risk aversion; online application; online app; resilience; wildland urban interface

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1. Introduction and Background

1.1. Economic Decision Guide Software (EDGe$) Online Tool Summary

The Economic Decision Guide Software (EDGe$) Online Tool provides an interactive online application for selecting cost-effective community resilience projects [1], leveraging the technique first introduced in the "Economic Decision Guide for buildings and infrastructure systems." [2-3]. EDGe$ is designed to support those engaged in community-level resilience planning, including community planners and resilience officers, as well as economic development, budget, and public works officials. It provides a standard economic methodology for evaluating investment decisions required to improve the ability of communities to adapt to, withstand, and quickly recover from natural, technology, and human-caused disruptive events. The tool helps to identify and compare the relevant present and future resilience net benefits/costs associated with capital investments versus maintaining a community's status-quo. The benefits identified include cost savings and damage loss avoidance because enhancing resilience on a community scale creates value, including co-benefits, even if a hazard event does not strike and externalities relevant to entities outside the community.

The ASTM E3130-21 Standard Guide for Developing Cost-Effective Community Resilience Strategies is the foundation for the methods of the "Economic Decision Guide" [2]. The use of EDGe$ is therefore consistent with this standard [1]. Furthermore, the ASTM E3350-22 Standard Guide for Community Resilience Planning for Buildings and Infrastructure reflects guidance in the NIST Community Resilience Planning Guide for Buildings and Infrastructure Systems [4] and references ASTM E3130-21. These two Standard Guides and the critical link between them, provide communities with consensus-based planning tools to increase resilience of the built environment and socioeconomic functions for all hazards and to assess the economic resilience benefits for the proposed projects developed through use of E3350-22.

To date, we are not aware of explicit treatment of loss amplification and are aware of only limited study of risk aversion in BCA tools and methods for assessing community resilience alternatives. The existing literature in risk aversion and BCA tools include studies into general flood risk and risk aversion and New Orleans, Hurricane Katrina case study flood risks and risk aversion [5-6]. Loss amplification and risk aversion considerations are not included in FEMA's BRIC assessment. This Special Publication provides a valuable work example to explore both these concepts and the important detail of considering options from differing perspectives (i.e., neighboring communities).

1.2. Loss Amplification Overview

Societal losses from extreme weather and climate events have been increasing since at least the 1960s [7]. In the period 2018-2022 there were 90 events that each cost $1 billion or more for a total loss of $619.3B [8]. The causes of these increases in losses are likely due to multiple factors, including increased development and encroachment into areas more vulnerable to natural hazards, and local and in some cases global increases in the rate of hazard events [9-10].

In particular, there have been large increases in WUI risk exposure over recent decades. From 1990 to 2010, the new WUI area in the U.S. has grown by 189 000km^2, an area slightly larger than the size of Washington state [11]. This area change represents a 33% increase in the total WUI area over that period. New WUI areas arise either when new houses are built in or near wildland vegetation or when wildland vegetation regrows in or near settled areas. Between these two possible causes, continued encroachment of human dwellings is the main cause for the expansion of WUI areas, with increases in vegetation contributing minimally [11].

During large (i.e., high cost/impact) natural hazard catastrophes, losses are often experienced by a relatively large portion of the local population. This often results in a demand surge for reconstruction and loss recovery activities immediately after the hazard event. The surge in demand increases the costs of reconstruction from their normal baseline rate by as much as 20% or more [12]. Without representing this demand surge in modeling, resilience plans underestimate losses and the costs of recovery activity after a disaster and can skew decision making unfavorably.

There is not specific literature we are aware of to document the use of amplification for mortality costs. Two methods are typically used for economic valuation of human loss: the willingness-to-pay method and human capital method. The value of statistical life (VSL) is based on the cost of mortality reduction implicit in societal regulatory and rulemaking practices; whereas the value an average person contributes to society along with a myriad of other factors, including age and productivity, in terms of accumulated compensation is the basis for the human capital method [13-15]. Literature does suggest that despite many analyses treating the VSL as a constant, there is variation expected in practice [16]. Age in the human capital method is specifically highlighted as a factor that could result in a heterogeneity of these values, specifically that younger children should be assigned high values. As for the willingness-to-pay method for mortality loss reduction, large variability in values are reported by many researchers [13]. If the average age of mortality or such variability are expected to skew the total loss for a community, mortality cost amplification could be justified, therefore we will present it, but will include a case to separate it from other loss cases.

One method to represent demand surges in catastrophe modeling is with loss amplification. Loss amplification calls for ordinary losses (O_L) or replacement costs to be multiplied by specific loss amplification factors (L_f) depending on the susceptibility of an area to catastrophic events. For example, a loss amplification factor of 2 results in a 100 % increase in ordinary losses and replacement costs.

$$Demand\ Surge\ Losses = O_L * L_f \tag{1}$$

Loss amplification factors can be derived from historical demand surge events, using local data, if available, or general hazard data transferred to the local context, if not. The demand surges in community home rebuilding, road and bridge construction, and other essential activities are associated with various large natural hazards such as Hurricane Katrina (10 - 40 %), earthquakes, wildfires, pandemics, and are well documented in the literature [17-20].

1.3. Risk Aversion Overview

Certainty is a rarity in any scientific, financial, or practical endeavor, and tolerance for uncertainty, or risk tolerance/aversion, varies from community to community. Planned and estimated costs for a public works project or almost any construction project at scale, and potential benefits, are notoriously uncertain. For an extreme example, expansion projects for nuclear power plants in the U.S. since 1970 have incurred an average 241 % overnight cost overrun (construction cost with no interest, as if completed overnight) compared to their initial estimated costs, and the beneficial power generation and carbon dioxide emission offsets they promised are often delayed by several years or more [21]. In addition to this ordinary budgeting uncertainty, disaster-based planning for natural hazards, including wildfires, necessitates modeling complex events with a multitude of influencing factors, triggering events and, ultimately, uncertainty in their occurrence frequency. Finally, some entities or communities are more risk tolerant than others, mostly based on their ability to tolerate the worst outcomes of the uncertainty in their planning. Therefore, it is desirable for an economic assessment tool, such as EDGe$, to not only handle uncertainty but to implement a mechanism where the uncertainty of different planning options and risk tolerance of the community can be weighed and assessed by some formal method.

The expected-utility hypothesis is a method of handling uncertainty or risk in a decision-making process by assigning an entity a utility function which maps expected payouts to an expected utility that the entity will realize from the payout [22]. The most basic utility function can map a completely linear relationship between payout and utility, where each marginal increase in payout results in the same marginal increase in utility at all payout levels. If a community or other entity has such a utility function, they are often called "risk-neutral." Such an entity will always make choices that result in the highest expected payout, regardless of the level of uncertainty involved. This contrasts with the "risk-averse" community or entity, which places a premium on being certain. The utility function of a risk-averse entity will still marginally increase, but at a decreasing rate for each marginal increase in payout. In other words, there is a diminishing return for such an entity to seek higher and higher levels of payout. If two options have no uncertainty, that entity will still derive higher utility from the option with higher payout, but if there is uncertainty in the payouts, they must be weighed against the utility function to determine which uncertain outcome maximizes the entity's utility.

The fundamental differential equations for representing the utility and risk aversion of an entity were laid out by Kenneth Joseph Arrow [23] and John W. Pratt [24]. They form the Arrow-Pratt measure of absolute risk aversion:

$$A(c) = -\frac{u''(x)}{u'(c)} \tag{2}$$

Where c is the expected payout, and $u(c)$ is the expected utility. For this case study, the constant relative risk aversion (CRRA), or isoelastic utility, a form of hyperbolic absolute risk aversion (HARA) is assumed as the utility function for a risk-averse entity. The general form of HARA is:

$$A(c) = \frac{1}{ac + b} \tag{3}$$

Where a and b are adjustable parameters. The solution for this differential equation is:

$$u(c) = \frac{(c - c_s)^{1-R}}{1 - R}, \text{where } R = \frac{1}{a}, c_s = -\frac{b}{a} \tag{4}$$

The form of HARA which follows the desired CRRA is where $b = 0$. The parameter a will be adjusted to represent different levels of risk aversion, where a larger a translates into less risk aversion, approaching risk-neutral as a approaches infinity. Using the CRRA equations with assumed parameters, the expected utility at each uncertain payout is used to derive a certainty equivalent payout, which provides the same expected utility as the uncertain payouts. A risk premium is also calculated, which is the difference between the certainty equivalent and the expected payout with uncertainty.

1.4. Presidential Library WUI Case Study Overview

The fictitious case study used for this report was initially developed for and described in NIST Special Publication 1260 [1]. The current Special Publication builds upon that analysis to include loss amplification and risk aversion parameters and analyses. While the study is based on best estimates for a fictitious case, and this report is not a recommended resilience plan for the named communities, the data used for the study is publicly available and based on real sources. The case study is a comparison of two different resilience development options for the Ronald Reagan Presidential Library (RRPL), from the perspective of two neighboring communities. The existing library was constructed in Simi Valley, California, and is in a "very high" fire hazard severity zone [25]. The expected rate of wildfire as with many other disasters, is uncertain, and in key locations in the United States wildfires are expected to be an increasing loss hazard due to increasingly dry conditions [26-27]. Given these two factors, wildfire planning is an ideal situation where loss amplification and risk aversion principles can be applied to enhance decision making.

The two communities from whose perspectives the development options will be analyzed are the home location of the existing library with a high wildfire risk (i.e., Simi Valley, CA) and a neighboring community outside of the WUI zone that is willing to fund a relocation of the library to itself (i.e., Oxnard, CA). Simi Valley's stake in the resilience planning and further development of the library is clear as the existing library's home community. Depending on the development option chosen for the library, they will contend with various direct and indirect costs, benefits, and externalities, as well as potential loss of life in their community due to wildfire disasters. As a neighboring community and potential host for a new library site, Oxnard has a stake in the development of the library and can incur similar direct and indirect costs, benefits, and externalities to the development choices made for the library.

The two development options considered in this analysis are: 1. To upgrade or retrofit the current library in situ or 2. To build a new library in Oxnard. The specifics of each option will be documented here as input data for EDGe$, and they are detailed more closely in SP1260 [1]. The retrofit option includes expenditures to mitigate the risk of wildfire disaster impacts, as well as to enhance the environmental impact characteristics of the existing structure. The new construction option moves the library to a lower risk wildfire zone thereby decreasing the need for extreme wildfire mitigation expenditures. It also allows for a lower environmental impact building to be constructed from the ground up. For the new construction option, the old library would be sold to a local university rather than be demolished.

2. Data Inputs for Loss Amplification and Risk Aversion Analysis

2.1. Benefits, Costs, and other EDGe$ Inputs and Outputs

The following data, in tables 1-20, is used in this special publication as inputs to demonstrate the potential addition of loss amplification and risk aversion to EDGe$, and BCA more generally. The rationale, original sources, and detailed information for the data can be found in SP1260 [1].

In addition, the following assumptions are also made to simplify this analysis. The planning horizon for both communities is assumed to be 50 years. The wildfire recurrence rate is assumed to be 40 years. A real discount rate of 7 % is used. The 7 % discount rate required in Circular A-4 is an estimate of the average before-tax rate of return to private capital in the U.S. economy, sometimes referred to as the social opportunity cost of capital [28]. The value of a statistical loss of life is assumed to be $7.9M. All one-time costs are assumed to occur in year zero. Recurring costs are annual and start at year one for the retrofit, and at year three for the new library.

Table 1. Losses to Simi Valley from wildfire damage to the RRPL

Category	Item	Estimate	Units
Direct	Structural	37 230	U.S. $1000
Indirect	Downtime	7 800	U.S. $1000
Indirect	Long-term	24 820	U.S. $1000
Response and Recovery	Evacuation	10 680	U.S. $1000
Fatalities	Lives lost	3	Lives

Table 2. Losses to Oxnard from wildfire damage to the RRPL

Category	Item	Estimate	Units
Indirect	Downtime	2 340	U.S. $1000
Indirect	Long-term	7 450	U.S. $1000
Response and Recovery	Evacuation	3 190	U.S. $1000

Table 3. Costs associated with retrofit for Simi Valley

Category	Item	Estimate	Cost	Units
Direct	Rooftop	$15.88 / sq ft (0.09 sq/m)	1 727	U.S. $1000
Direct	Roof Lining	$45.55 / ft (0.30 m)	138	U.S. $1000
Direct	Exterior Wall	$30.18 / sq ft (0.09 sq/m)	1 223	U.S. $1000
Direct	Landscaping	$2.07 / sq ft (0.09 sq/m)	1 502	U.S. $1000
Direct	Green Retrofit	$7 / sq ft (0.09 sq/m)	1 701	U.S. $1000
Indirect	Downtime	$150 000 / week	4 500	U.S. $1000

Table 4. Oxnard costs associated with new library

Category	Item	Estimate	Cost	Units
Direct	Building	99.01 % of original construction cost	100 003	U.S. $1000
Direct	Land	$100 000 / acre	10 000	U.S. $1000
Annual Operation Maintenance and Repair (OMR)	Operations	86 % of original OMR	2 173	U.S. $1000 per year

Table 5. Simi Valley costs associated with new library

Category	Item	Estimate	Cost	Units
Direct	Historical Value	15 x base valuation	100 983	U.S. $1000
Indirect	Resale	assumed	(56 500)	U.S. $1000
Annual Operation Maintenance and Repair (OMR)	Operations	full original cost	(2 528)	U.S. $1000 per year

Table 6. Simi Valley reductions in wildfire losses for retrofit

Loss category	Loss reduction
Direct	60.00 %
Indirect	60.00 %
Response and recovery (R&R)	20.00 %
Fatalities	1 Life

Table 7. Simi Valley non-disaster related benefits for retrofit

Item	Calculations	Benefit	Units
Asset Value	50 % of wildfire retrofit cost 6 % overall asset value increase	6 464	U.S. $1000
Noise Reduction	0.1 % property value per decibel	1 299	U.S. $1000
Energy Savings	14 % of OMR	354	U.S. $1000 per year
Maintenance Costs	10 % of OMR	253	U.S. $1000 per year
Productivity	$0.535 per meter2 ($0.050 per ft.2)	1 400	U.S. $1000 per year
Construction Earnings	57.8 % of construction spending	5 375	U.S. $1000

Table 8. Oxnard reductions in wildfire losses for retrofit

Loss category	Loss reduction
Direct	100.00 %
Indirect	100.00 %
Response and recovery (R&R)	100.00 %
Fatalities	3 Lives

Table 9. Oxnard non-disaster related benefits for new library

Item	Calculations	Benefit	Units
Payroll	48.5 % of spending	4 651	U.S. $1000
Non-Payroll	90 % of spending	6 384	U.S. $1000
Tourism	$107.82 per net new visitor	17 918	U.S. $1000
Construction Earnings	57.8 % of construction spending	57 807	U.S. $1000
Productivity	$0.535 per sq meter	1 400	U.S. $1000

Table 10. Simi Valley non-disaster related benefits for new library

Item	Calculations	Benefit	Units
Library Access	$ 18.68 per visitor	(1 560)	U.S. $1000
Tourism	$ 107.82 per net new visitor	(15 297)	U.S. $1000
Students Residents	$ 12 790.91 per student	12 791	U.S. $1000

Table 11. Externalities for Simi Valley and Oxnard

Perspective	Retrofit	New Library	Units
Simi Valley (Net Impact on Oxnard)	985	251 833	U.S. $1000
Oxnard (Net Impact on Simi Valley)	41 552	(40 124)	U.S. $1000

Table 12. Cost input values for EDGe$ for Simi Valley

Cost Category	Cost	Retrofit	New Library	Units
Direct	Construction	6 291	-	U.S. $1000
Direct	Historical Value	-	100 983	U.S. $1000
Indirect	Downtime	4 500	-	U.S. $1000
Indirect	Resale	-	(56 500)	U.S. $1000
OMR	Operations	-	(2528)	U.S. $1000

Table 13. Wildfire related loss reduction input for EDGe$ for Simi Valley

Loss Category	Retrofit	New Library	Units
Direct Loss Reduction	22 338	37 230	U.S. $1000
Indirect Loss Reduction	19 572	32 620	U.S. $1000
R&R Reduction	2136	10 680	U.S. $1000
Fatalities Averted	1	3	Lives

Table 14. Non-disaster related benefit input for EDGe$ for Simi Valley

Loss Category	Retrofit	New Library	Units
Asset Value	7 763	-	U.S. $1000
Operation Costs	607	-	U.S. $1000 per year
Productivity	1 400	-	U.S. $1000 per year
Construction Earnings	5 375	-	U.S. $1000
Library Access	-	(1 560)	U.S. $1000 per year
Tourism	-	(15 297)	U.S. $1000 per year
Student Visits	-	12 791	U.S. $1000 per year

Table 15. EDGe$ output for Simi Valley

Items	Retrofit	New Library	Units
Disaster Economic Benefits			
Response and Recovery Costs	759	3797	U.S. $1000
Direct Loss Reduction	7 942	13 236	U.S. $1000
Indirect Losses	6 958	11 597	U.S. $1000
Disaster Non-Market Benefits			
Value of Statistical Lives Saved	2 809	8426	U.S. $1000
Number of Statistical Lives Saved	1.25	3.75	Lives
Non-Disaster Related Benefits			
One-Time	11 422	-	U.S. $1000
Recurring	24 965	(38 666)	U.S. $1000 per year
Costs			
Direct Costs	6 291	100 983	U.S. $1000
Indirect Costs	4 500	(56 500)	U.S. $1000
OMR			
One-Time	-	-	U.S. $1000
Recurring	-	(33 811)	U.S. $1000 per year
Externalities			
Positive			
One-Time	985	251 833	U.S. $1000
Recurring	-	-	U.S. $1000 per year
Negative			
One-Time	-	-	U.S. $1000
Recurring	-	-	U.S. $1000 per year
Present Expected Value			
Benefits	54 855	(1 606)	U.S. $1000
Costs	10 791	10 672	U.S. $1000
Externalities	985	251 833	U.S. $1000
Net (NPV) with Externalities	45 049	239 555	U.S. $1000
Benefit-to-Cost Ratio (BCR) with Externalities	5.17	23.45	Ratio
Internal Rate of Return with Externalities (%)	53.54	-5.56	%
Return on Investment with Externalities (%)	8.35	44.89	%
Non-Disaster ROI with Externalities (%)	4.93	37.95	%
Net (NPV) without Externalities	44 064	(12 278)	U.S. $1000
Benefit-to-Cost Ratio (BCR)	5.08	-0.15	Ratio
Internal Rate of Return (%)	59.5	3.02	%
Return on Investment (%)	8.17	-2.30	%
Non-Disaster ROI (%)	4.74	-9.25	%

Table 16. Cost input values for EDGe$ for Oxnard

Cost Category	Cost	Retrofit	New Library	Units
Direct	Building	-	100 003	U.S. $1000
Direct	Land	-	10 000	U.S. $1000
Indirect	Downtime	1 350	-	U.S. $1000
Indirect	None			
OMR	Operations	-	(2 528)	U.S. $1000

Table 17. Wildfire related loss reduction input for EDGe$ for Oxnard

Loss Category	Retrofit	New Library	Units
Direct Loss Reduction	-	-	U.S. $1000
Indirect Loss Reduction	5 874	9 790	U.S. $1000
R&R Reduction	638	3 190	U.S. $1000
Fatalities Averted	0	0	Lives

Table 18. Non-disaster related benefit input for EDGe$ for Oxnard

Loss Category	Retrofit	New Library	Units
Library expenses	-	11 035	U.S. $1000 per year
Tourism	-	17 918	U.S. $1000 per year
Construction earnings	-	57 807	U.S. $1000 per year
Productivity	-	1 400	U.S. $1000 per year

Table 19. Externality input for Oxnard

Externality	Retrofit	New Library	Units
Impact on Simi Valley	1 552	(40 124)	U.S. $1000

Table 20. EDGe$ output for Oxnard

Items	Retrofit	New Library	Units
Disaster Economic Benefits			
Response and Recovery Costs	227	1 134	U.S. $1000
Direct Loss Reduction	-	-	U.S. $1000
Indirect Losses	2 088	3 481	U.S. $1000
Disaster Non-Market Benefits			
Value of Statistical Lives Saved	-	-	U.S. $1000
Number of Statistical Lives Saved	0	0	Lives
Non-Disaster Related Benefits			
One-Time	-	54 009	U.S. $1000
Recurring	-	405 974	U.S. $1000 per year
Costs			
Direct Costs	-	10 003	U.S. $1000
Indirect Costs	1 350	-	U.S. $1000
OMR			
One-Time	-	-	U.S. $1000
Recurring	-	(23 398)	U.S. $1000 per year
Externalities			
Positive			
One-Time	41 552		U.S. $1000
Recurring	-	-	U.S. $1000 per year
Negative			
One-Time	-	(40 124)	U.S. $1000
Recurring	-	-	U.S. $1000 per year
Present Expected Value			
Benefits	2 315	464 598	U.S. $1000
Costs	1 350	86 605	U.S. $1000
Externalities	41 552	(40 124)	U.S. $1000
Net (NPV) with Externalities	42 517	337 869	U.S. $1000
Benefit-to-Cost Ratio (BCR) with Externalities	32.49	4.90	Ratio
Internal Rate of Return with Externalities (%)	-5.47	26.05	%
Return on Investment with Externalities (%)	62.99	7.80	%
Non-Disaster ROI with Externalities (%)	59.56	7.70	%
Net (NPV) without Externalities	965	377 993	U.S. $1000
Benefit-to-Cost Ratio (BCR)	1.71	5.36	Ratio
Internal Rate of Return (%)	12.03	36.81	%
Return on Investment (%)	1.43	8.73	%
Non-Disaster ROI (%)	-2.00	8.62	%

3. Loss Amplification Analysis

3.1. Different Loss Amplification Types and Levels

For this WUI case study, loss amplification is applied at different levels and for different subtypes of losses. This way, the effect of the amplification can be observed on the outputs of the benefit-cost analysis (BCA) and net present value (NPV) computations of the two communities and their two development options for the RRPL.

The loss amplification factors, and types of amplifications considered and trialed in the WUI Case study analysis are listed in Table 22. The baseline is where no loss amplification occurs (i.e., where the loss amplification factor is 1) and loss amplification factors from 1.5 to 3.0 are applied in 0.5 increments. These factors were chosen because limited data exists for the documentation of demand surge, and we wanted to demonstrate for trend exploring purposes the effect of large amplification factors. The data that was found reports a wide margin of demand surge, as low as 10 % (1.1) or as high as 50 % (1.5) [12]. Other research indicates that this range is highly variable and is dependent on a wide array of factors, such as whether the construction industry is in a growth cycle thus having little extra supply, or whether there is a high percentage of insurance claims pushing demand higher [29]. Loss amplification factors both above and below the observed ranges, and below baseline, are trialed to observe the parametric effects of loss amplification outside currently observed ranges, particularly given the limited quantification of demand surge effects more broadly.

There are three types of amplification, which dictate to which types of losses and costs the factors are applied. Type 1 assumes only property loss amplification. Type 2 assumes only mortality and cost amplification. Type 3 combines type 1 and type 2 to apply the factors to all losses, costs, and mortality. In many cases, and for our case study in particular, benefits take the form of loss reductions during/following a disaster event, and therefore these benefits are also amplified for some cases.

Table 21. Loss amplification subtype cases and amplification levels

Attribute	Baseline: Loss Neutral	Type 1: Property Loss Amplification		Type 2: Mortality and Cost Amplification		Type 3: Combined Amplification	
Name	No Loss Amplification	Type 1a: Simi Valley	Type 1b: Oxnard	Type 2a: Simi Valley	Type 2b: Oxnard	Type 3a: Simi Valley	Type 3b: Oxnard
Factor type							
Disaster Economic Benefits							
Response and Recovery Costs	1	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	1	1	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment
Direct Loss Reduction	1	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	1	1	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment
Indirect Losses	1	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	1	1	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment
Disaster Non-Market Benefits							
Value of Statistical Lives Saved	1	1	1	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment
Number of Statistical Lives Saved	1	1	1	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment
Non-Disaster Related Benefits							
One-Time	1	1	1	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment
Recurring	1	1	1	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment
Costs							
Direct Costs	1	1	1	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment
Indirect Costs	1	1	1	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment
OMR							
One-Time	1	1	1	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment
Recurring	1	1	1	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment	0.5 to 3, 0.5 increment
Externalities							
Positive							
One-Time	1	1	1	1	1	1	1
Recurring	1	1	1	1	1	1	1
Negative							
One-Time	1	1	1	1	1	1	1
Recurring	1	1	1	1	1	1	1

The EDGe$ outputs from table 16 and 21 produced through the cases of loss amplification computations are detailed in Tables 22-36.

Table 22. Example property loss amplification (types 1a and 1b) at a loss factor of 0.5

Items	Units	Loss Factor	Simi Valley Retrofit	Simi Valley New Library	Oxnard Retrofit	Oxnard New Library
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	0.5	380	1 899	113	567
Direct Loss Reduction	U.S. $1000	0.5	3 971	6 618	-	-
Indirect Losses	U.S. $1000	0.5	3 479	5 799	1 044	1 740
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	1.0	2 809	8 426	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	1.0	6 291	100 983	-	110 003
Indirect Costs	U.S. $1000	1.0	4 500	(56 500)	1 350	-
OMR						
One-Time	U.S. $1000	1.0	-	-	-	-
Recurring	U.S. $1000 per year	1.0	-	(33 811)	-	(23 398)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		47 026	(15 921)	1 158	462 290
Costs	U.S. $1000		10 791	10 672	1 350	86 605
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		37 220	225 240	41 360	335 561
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		4.45	22.11	31.64	4.87
Return on Investment with Externalities (%)	%		6.90	42.21	61.27	7.75
Non-Disaster ROI with Externalities (%)	%		4.93	37.95	59.56	7.70
Net (NPV) without Externalities	U.S. $1000		36 235	(26 593)	(192)	375 685
Benefit-to-Cost Ratio (BCR)	Ratio		4.36	-1.49	0.86	5.34
Return on Investment (%)	%		6.72	-4.98	-0.29	8.68
Non-Disaster ROI (%)	%		4.74	-9.25	-2.00	8.62

Table 23. Example property loss amplification (types 1a and 1b) at a loss factor of 1.5

Items	Units	Loss Factor	Simi Valley Retrofit	Simi Valley New Library	Oxnard Retrofit	Oxnard New Library
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	1.5	1 139	5 696	340	1 701
Direct Loss Reduction	U.S. $1000	1.5	11 913	19 854	-	-
Indirect Losses	U.S. $1000	1.5	10 437	17 396	3 133	5 221
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	1.0	2 809	8 426	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	1.0	6 291	100 983	-	110 003
Indirect Costs	U.S. $1000	1.0	4 500	(56 500)	1 350	-
OMR						
One-Time	U.S. $1000	1.0	-	-	-	-
Recurring	U.S. $1000 per year	1.0	-	(33 811)	-	(23 398)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		62 686	12 710	3 473	466 905
Costs	U.S. $1000		10 791	10 672	1 350	86 605
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		52 880	253 871	43 675	340 176
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		5.90	24.79	33.35	4.93
Return on Investment with Externalities (%)	%		9.80	47.58	64.70	7.86
Non-Disaster ROI with Externalities (%)	%		4.93	37.95	59.56	7.70
Net (NPV) without Externalities	U.S. $1000		51 895	2 038	2 123	380 300
Benefit-to-Cost Ratio (BCR)	Ratio		5.81	1.19	2.57	5.39
Return on Investment (%)	%		9.62	0.38	3.14	8.78
Non-Disaster ROI (%)	%		4.74	-9.25	-2.00	8.62

Table 24. Example property loss amplification (types 1a and 1b) at a loss factor of 2.0

Items	Units	Loss Factor	Simi Valley Retrofit	Simi Valley New Library	Oxnard Retrofit	Oxnard New Library
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	2.0	1 519	7 594	454	2 268
Direct Loss Reduction	U.S. $1000	2.0	15 883	26 472	-	-
Indirect Losses	U.S. $1000	2.0	13 917	23 194	4 177	6 961
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	1.0	2 809	8 426	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	1.0	6 291	100 983	-	110 003
Indirect Costs	U.S. $1000	1.0	4 500	(56 500)	1 350	-
OMR						
One-Time	U.S. $1000	1.0	-	-	-	-
Recurring	U.S. $1000 per year	1.0	-	(33 811)	-	(23 398)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		70 515	27 025	4 630	469 212
Costs	U.S. $1000		10 791	10 672	1 350	86 605
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		60 709	268 186	44 832	342 483
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		6.63	26.13	34.21	4.95
Return on Investment with Externalities (%)	%		11.25	50.26	66.42	7.91
Non-Disaster ROI with Externalities (%)	%		4.93	37.95	59.56	7.70
Net (NPV) without Externalities	U.S. $1000		59 724	16 353	3 280	382 607
Benefit-to-Cost Ratio (BCR)	Ratio		6.53	2.53	3.43	5.42
Return on Investment (%)	%		11.07	3.06	4.86	8.84
Non-Disaster ROI (%)	%		4.74	-9.25	-2.00	8.62

Table 25. Example property loss amplification (types 1a and 1b) at a loss factor of 2.5

Items	Units	Loss Factor	Simi Valley Retrofit	Simi Valley New Library	Oxnard Retrofit	Oxnard New Library
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	2.5	1 899	9 493	567	2 835
Direct Loss Reduction	U.S. $1000	2.5	19 854	33 090	-	-
Indirect Losses	U.S. $1000	2.5	17 396	28 993	5 221	8 701
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	1.0	2 809	8 426	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	1.0	6 291	100 983	-	110 003
Indirect Costs	U.S. $1000	1.0	4 500	(56 500)	1 350	-
OMR						
One-Time	U.S. $1000	1.0	-	-	-	-
Recurring	U.S. $1000 per year	1.0	-	(33 811)	-	(23 398)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		78 345	41 340	5 788	471 520
Costs	U.S. $1000		10 791	10 672	1 350	86 605
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		68 539	282 501	45 990	344 791
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		7.35	27.47	35.07	4.98
Return on Investment with Externalities (%)	%		12.70	52.94	68.13	7.96
Non-Disaster ROI with Externalities (%)	%		4.93	37.95	59.56	7.70
Net (NPV) without Externalities	U.S. $1000		67 554	30 668	4 438	384 915
Benefit-to-Cost Ratio (BCR)	Ratio		7.26	3.87	4.29	5.44
Return on Investment (%)	%		12.52	5.75	6.57	8.89
Non-Disaster ROI (%)	%		4.74	-9.25	-2.00	8.62

Table 26. Example property loss amplification (types 1a and 1b) at a loss factor of 3.0

Items	Units	Loss Factor	Simi Valley Retrofit	Simi Valley New Library	Oxnard Retrofit	Oxnard New Library
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	3.0	2 278	11 391	680	3 402
Direct Loss Reduction	U.S. $1000	3.0	23 825	39 709	-	-
Indirect Losses	U.S. $1000	3.0	20 875	34 792	6 265	10 442
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	1.0	2 809	8 426	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	1.0	6 291	100 983	-	110 003
Indirect Costs	U.S. $1000	1.0	4 500	(56 500)	1 350	-
OMR						
One-Time	U.S. $1000	1.0	-	-	-	-
Recurring	U.S. $1000 per year	1.0	-	(33 811)	-	(23 398)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		86 175	55 655	6 946	473 827
Costs	U.S. $1000		10 791	10 672	1 350	86 605
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		76 369	296 816	47 148	347 098
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		8.08	28.81	35.92	5.01
Return on Investment with Externalities (%)	%		14.15	55.63	69.85	8.02
Non-Disaster ROI with Externalities (%)	%		4.93	37.95	59.56	7.70
Net (NPV) without Externalities	U.S. $1000		75 384	44 983	5 596	387 222
Benefit-to-Cost Ratio (BCR)	Ratio		7.99	5.22	5.14	5.47
Return on Investment (%)	%		13.97	8.43	8.29	8.94
Non-Disaster ROI (%)	%		4.74	-9.25	-2.00	8.62

Table 27. Example mortality and cost amplification (types 2a and 2b) at a loss factor of 0.5

Items	Units	Loss Factor	Simi Valley Retrofit	Simi Valley New Library	Oxnard Retrofit	Oxnard New Library
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	1.0	759	3 797	227	1 134
Direct Loss Reduction	U.S. $1000	1.0	7 942	13 236	-	-
Indirect Losses	U.S. $1000	1.0	6 958	11 597	2 088	3 481
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	0.5	1 404	4 213	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	0.5	3 146	50 492	-	55 002
Indirect Costs	U.S. $1000	0.5	2 250	(28 250)	675	-
OMR						
One-Time	U.S. $1000	0.5	-	-	-	-
Recurring	U.S. $1000 per year	0.5	-	(16 906)	-	(11 699)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		53 452	(5 819)	2 315	464 598
Costs	U.S. $1000		5 396	5 336	675	43 303
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		49 041	240 678	43 192	381 171
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		10.09	46.10	64.99	9.80
Return on Investment with Externalities (%)	%		18.18	90.21	127.98	17.61
Non-Disaster ROI with Externalities (%)	%		11.85	77.90	121.12	17.39
Net (NPV) without Externalities	U.S. $1000		48 056	(11 155)	1 640	421 295
Benefit-to-Cost Ratio (BCR)	Ratio		9.91	-1.09	3.43	10.73
Return on Investment (%)	%		17.81	-4.18	4.86	19.46
Non-Disaster ROI (%)	%		11.49	-16.49	-2.00	19.25

Table 28. Example mortality and cost amplification (types 2a and 2b) at a loss factor of 1.5

Items	Units	Loss Factor	Simi Valley Retrofit	Simi Valley New Library	Oxnard Retrofit	Oxnard New Library
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	1.0	759	3 797	227	1 134
Direct Loss Reduction	U.S. $1000	1.0	7 942	13 236	-	-
Indirect Losses	U.S. $1000	1.0	6 958	11 597	2 088	3 481
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	1.5	4 213	12 639	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	1.5	9 437	151 475	-	165 005
Indirect Costs	U.S. $1000	1.5	6 750	(84 750)	2 025	-
OMR						
One-Time	U.S. $1000	1.5	-	-	-	-
Recurring	U.S. $1000 per year	1.5	-	(50 717)	-	(35 097)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		56 260	2 607	2 315	464 598
Costs	U.S. $1000		16 187	16 008	2 025	129 908
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		41 059	238 432	41 842	294 566
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		3.54	15.89	21.66	3.27
Return on Investment with Externalities (%)	%		5.07	29.79	41.33	4.54
Non-Disaster ROI with Externalities (%)	%		2.62	24.63	39.04	4.46
Net (NPV) without Externalities	U.S. $1000		40 074	(13 401)	290	334 690
Benefit-to-Cost Ratio (BCR)	Ratio		3.48	0.16	1.14	3.58
Return on Investment (%)	%		4.95	-1.67	0.29	5.15
Non-Disaster ROI (%)	%		2.50	-6.83	-2.00	5.08

Table 29. Example mortality and cost amplification (types 2a and 2b) at a loss factor of 2.0

Items	Units	Loss Factor	Simi Valley Retrofit	Simi Valley New Library	Oxnard Retrofit	Oxnard New Library
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	1.0	759	3 797	227	1 134
Direct Loss Reduction	U.S. $1000	1.0	7 942	13 236	-	-
Indirect Losses	U.S. $1000	1.0	6 958	11 597	2 088	3 481
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	2.0	5 617	16 852	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	2.0	12 582	201 966	-	220 006
Indirect Costs	U.S. $1000	2.0	9 000	(113 000)	2 700	-
OMR						
One-Time	U.S. $1000	2.0	-	-	-	-
Recurring	U.S. $1000 per year	2.0	-	(67 622)	-	(46 796)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		57 665	6 820	2 315	464 598
Costs	U.S. $1000		21 582	21 344	2 700	173 210
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		37 068	237 309	41 167	251 264
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		2.72	12.12	16.25	2.45
Return on Investment with Externalities (%)	%		3.44	22.24	30.49	2.90
Non-Disaster ROI with Externalities (%)	%		1.46	17.97	28.78	2.85
Net (NPV) without Externalities	U.S. $1000		36 083	(14 524)	(385)	291 388
Benefit-to-Cost Ratio (BCR)	Ratio		2.67	0.32	0.86	2.68
Return on Investment (%)	%		3.34	-1.36	-0.29	3.36
Non-Disaster ROI (%)	%		1.37	-5.62	-2.00	3.31

Table 30. Example mortality and cost amplification (types 2a and 2b) at a loss factor of 2.5

Items	Units	Loss Factor	Simi Valley Retrofit	Simi Valley New Library	Oxnard Retrofit	Oxnard New Library
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	1.0	759	3 797	227	1 134
Direct Loss Reduction	U.S. $1000	1.0	7 942	13 236	-	-
Indirect Losses	U.S. $1000	1.0	6 958	11 597	2 088	3 481
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	2.5	7 022	21 065	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	2.5	15 728	252 458	-	275 008
Indirect Costs	U.S. $1000	2.5	11 250	(141 250)	3 375	-
OMR						
One-Time	U.S. $1000	2.5	-	-	-	-
Recurring	U.S. $1000 per year	2.5	-	(84 528)	-	(58 495)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		59 069	11 033	2 315	464 598
Costs	U.S. $1000		26 978	26 680	3 375	216 513
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		33 076	236 186	40 492	207 961
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		2.23	9.85	13.00	1.96
Return on Investment with Externalities (%)	%		2.45	17.71	24.00	1.92
Non-Disaster ROI with Externalities (%)	%		0.77	13.98	22.62	1.88
Net (NPV) without Externalities	U.S. $1000		32 091	(15 647)	(1 060)	248 085
Benefit-to-Cost Ratio (BCR)	Ratio		2.19	0.41	0.69	2.15
Return on Investment (%)	%		2.38	-1.17	-0.63	2.29
Non-Disaster ROI (%)	%		0.70	-4.90	-2.00	2.25

Table 31. Example mortality and cost amplification (types 2a and 2b) at a loss factor of 3.0

Items	Units	Loss Factor	Simi Valley Retrofit	Simi Valley New Library	Oxnard Retrofit	Oxnard New Library
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	1.0	759	3 797	227	1 134
Direct Loss Reduction	U.S. $1000	1.0	7 942	13 236	-	-
Indirect Losses	U.S. $1000	1.0	6 958	11 597	2 088	3 481
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	3.0	8 426	25 278	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	3.0	18 873	302 949	-	330 009
Indirect Costs	U.S. $1000	3.0	13 500	(169 500)	4 050	-
OMR						
One-Time	U.S. $1000	3.0	-	-	-	-
Recurring	U.S. $1000 per year	3.0	-	(101 433)	-	(70 194)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		60 473	15 246	2 315	464 598
Costs	U.S. $1000		32 373	32 016	4 050	259 815
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		29 085	235 063	39 817	164 659
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		1.90	8.34	10.83	1.63
Return on Investment with Externalities (%)	%		1.80	14.68	19.66	1.27
Non-Disaster ROI with Externalities (%)	%		0.31	11.32	18.52	1.23
Net (NPV) without Externalities	U.S. $1000		28 100	(16 770)	(1 735)	204 783
Benefit-to-Cost Ratio (BCR)	Ratio		1.87	0.48	0.57	1.79
Return on Investment (%)	%		1.74	-1.05	-0.86	1.58
Non-Disaster ROI (%)	%		0.25	-4.42	-2.00	1.54

Table 32. Example combined amplification (types 3a and 3b) at a loss factor of 0.5

Items	Units	Loss Factor	Simi Valley Retrofit	Simi Valley New Library	Oxnard Retrofit	Oxnard New Library
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	0.5	380	1 899	113	567
Direct Loss Reduction	U.S. $1000	0.5	3 971	6 618	-	-
Indirect Losses	U.S. $1000	0.5	3 479	5 799	1 044	1 740
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	0.5	1 404	4 213	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	0.5	3 146	50 492	-	55 002
Indirect Costs	U.S. $1000	0.5	2 250	(28 250)	675	-
OMR						
One-Time	U.S. $1000	0.5	-	-	-	-
Recurring	U.S. $1000 per year	0.5	-	(16 906)	-	(11 699)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		45 622	(20 134)	1 158	462 290
Costs	U.S. $1000		5 396	5 336	675	43 303
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		41 211	226 363	42 035	378 864
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		8.64	43.42	63.27	9.75
Return on Investment with Externalities (%)	%		15.28	84.84	124.55	17.50
Non-Disaster ROI with Externalities (%)	%		11.85	77.90	121.12	17.39
Net (NPV) without Externalities	U.S. $1000		40 226	(25 470)	483	418 988
Benefit-to-Cost Ratio (BCR)	Ratio		8.46	-3.77	1.71	10.68
Return on Investment (%)	%		14.91	-9.55	1.43	19.35
Non-Disaster ROI (%)	%		11.49	-16.49	-2.00	19.25

Table 33. Example combined amplification (types 3a and 3b) at a loss factor of 1.5

Items	Units	Loss Factor	Simi Valley Retrofit	Simi Valley New Library	Oxnard Retrofit	Oxnard New Library
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	1.5	1 139	5 696	340	1 701
Direct Loss Reduction	U.S. $1000	1.5	11 913	19 854	-	-
Indirect Losses	U.S. $1000	1.5	10 437	17 396	3 133	5 221
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	1.5	4 213	12 639	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	1.5	9 437	151 475	-	165 005
Indirect Costs	U.S. $1000	1.5	6 750	(84 750)	2 025	-
OMR						
One-Time	U.S. $1000	1.5	-	-	-	-
Recurring	U.S. $1000 per year	1.5	-	(50 717)	-	(35 097)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		64 090	16 923	3 473	466 905
Costs	U.S. $1000		16 187	16 008	2 025	129 908
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		48 888	252 748	43 000	296 873
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		4.02	16.79	22.23	3.29
Return on Investment with Externalities (%)	%		6.04	31.58	42.47	4.57
Non-Disaster ROI with Externalities (%)	%		2.62	24.63	39.04	4.46
Net (NPV) without Externalities	U.S. $1000		47 903	915	1 448	336 997
Benefit-to-Cost Ratio (BCR)	Ratio		3.96	1.06	1.71	3.59
Return on Investment (%)	%		5.92	0.11	1.43	5.19
Non-Disaster ROI (%)	%		2.50	-6.83	-2.00	5.08

Table 34. Example combined amplification (types 3a and 3b) at a loss factor of 2.0

Items	Units	Loss Factor	Simi Valley Retrofit	Simi Valley New Library	Oxnard Retrofit	Oxnard New Library
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	2.0	1 519	7 594	454	2 268
Direct Loss Reduction	U.S. $1000	2.0	15 883	26 472	-	-
Indirect Losses	U.S. $1000	2.0	13 917	23 194	4 177	6 961
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	2.0	5 617	16 852	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	2.0	12 582	201 966	-	220 006
Indirect Costs	U.S. $1000	2.0	9 000	(113 000)	2 700	-
OMR						
One-Time	U.S. $1000	2.0	-	-	-	-
Recurring	U.S. $1000 per year	2.0	-	(67 622)	-	(46 796)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		73 324	35 451	4 630	469 212
Costs	U.S. $1000		21 582	21 344	2 700	173 210
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		52 727	265 940	43 482	255 878
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		3.44	13.46	17.10	2.48
Return on Investment with Externalities (%)	%		4.89	24.92	32.21	2.95
Non-Disaster ROI with Externalities (%)	%		1.46	17.97	28.78	2.85
Net (NPV) without Externalities	U.S. $1000		51 742	14 107	1 930	296 002
Benefit-to-Cost Ratio (BCR)	Ratio		3.40	1.66	1.71	2.71
Return on Investment (%)	%		4.79	1.32	1.43	3.42
Non-Disaster ROI (%)	%		1.37	-5.62	-2.00	3.31

Table 35. Example combined amplification (types 3a and 3b) at a loss factor of 2.5

			Simi Valley		Oxnard	
Items	**Units**	**Loss Factor**	**Retrofit**	**New Library**	**Retrofit**	**New Library**
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	2.5	1 899	9 493	567	2 835
Direct Loss Reduction	U.S. $1000	2.5	19 854	33 090	-	-
Indirect Losses	U.S. $1000	2.5	17 396	28 993	5 221	8 701
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	2.5	7 022	21 065	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	2.5	15 728	252 458	-	275 008
Indirect Costs	U.S. $1000	2.5	11 250	(141 250)	3 375	-
OMR						
One-Time	U.S. $1000	2.5	-	-	-	-
Recurring	U.S. $1000 per year	2.5	-	(84 528)	-	(58 495)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		82 558	53 979	5 788	471 520
Costs	U.S. $1000		26 978	26 680	3 375	216 513
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		56 566	279 132	43 965	214 883
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		3.10	11.46	14.03	1.99
Return on Investment with Externalities (%)	%		4.19	20.92	26.05	1.98
Non-Disaster ROI with Externalities (%)	%		0.77	13.98	22.62	1.88
Net (NPV) without Externalities	U.S. $1000		55 581	27 299	2 413	255 007
Benefit-to-Cost Ratio (BCR)	Ratio		3.06	2.02	1.71	2.18
Return on Investment (%)	%		4.12	2.05	1.43	2.36
Non-Disaster ROI (%)	%		0.70	-4.90	-2.00	2.25

Table 36. Example combined amplification (types 3a and 3b) at a loss factor of 3.0

Items	Units	Loss Factor	Simi Valley Retrofit	Simi Valley New Library	Oxnard Retrofit	Oxnard New Library
Disaster Economic Benefits						
Response and Recovery Costs	U.S. $1000	3.0	2 278	11 391	680	3 402
Direct Loss Reduction	U.S. $1000	3.0	23 825	39 709	-	-
Indirect Losses	U.S. $1000	3.0	20 875	34 792	6 265	10 442
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	U.S. $1000	3.0	8 426	25 278	-	-
Number of Statistical Lives Saved	Count	1.0	1.25	3.75	-	-
Non-Disaster Related Benefits						
One-Time	U.S. $1000	1.0	11 422	-	-	54 009
Recurring	U.S. $1000 per year	1.0	24 965	(38 666)	-	405 974
Costs			-	-	-	-
Direct Costs	U.S. $1000	3.0	18 873	302 949	-	330 009
Indirect Costs	U.S. $1000	3.0	13 500	(169 500)	4 050	-
OMR						
One-Time	U.S. $1000	3.0	-	-	-	-
Recurring	U.S. $1000 per year	3.0	-	(101 433)	-	(70 194)
Externalities						
Positive						
One-Time	U.S. $1000	1.0	985	251 833	41 552	-
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Negative				-	-	-
One-Time	U.S. $1000	1.0	-	-	-	(40 124)
Recurring	U.S. $1000 per year	1.0	-	-	-	-
Present Expected Value						
Benefits	U.S. $1000		91 792	72 507	6 946	473 827
Costs	U.S. $1000		32 373	32 016	4 050	259 815
Externalities	U.S. $1000		985	251 833	41 552	(40 124)
Net (NPV) with Externalities	U.S. $1000		60 404	292 324	44 448	173 888
Benefit-to-Cost Ratio (BCR) with Externalities	Ratio		2.87	10.13	11.97	1.67
Return on Investment with Externalities (%)	%		3.73	18.26	21.95	1.34
Non-Disaster ROI with Externalities (%)	%		0.31	11.32	18.52	1.23
Net (NPV) without Externalities	U.S. $1000		59 419	40 491	2 896	214 012
Benefit-to-Cost Ratio (BCR)	Ratio		2.84	2.26	1.71	1.82
Return on Investment (%)	%		3.67	2.53	1.43	1.65
Non-Disaster ROI (%)	%		0.25	-4.42	-2.00	1.54

3.2. Impact On Case Study for Different Loss Amplification Factors and Types

The effects of the different types of loss amplification analysis for the WUI case study on key economic indicators are summarized in the following Figs. 1, 2 and 3. These figures detail ratios which are formed from the outputs of edges (NPV, BCR and ROI, all with externalities) with amplification at different levels compared to those same outputs from the base case with no amplification.

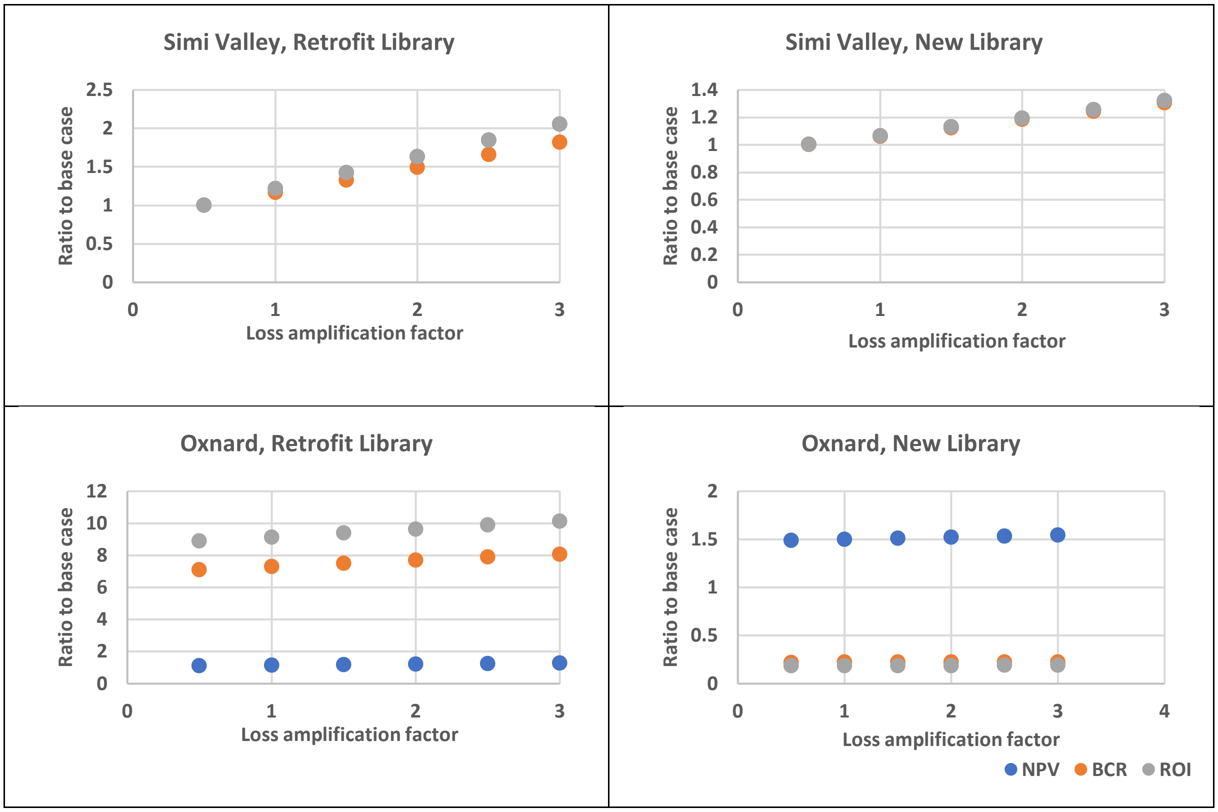

Figure 1. Property Loss amplification effect on key EDGe$ analysis outputs

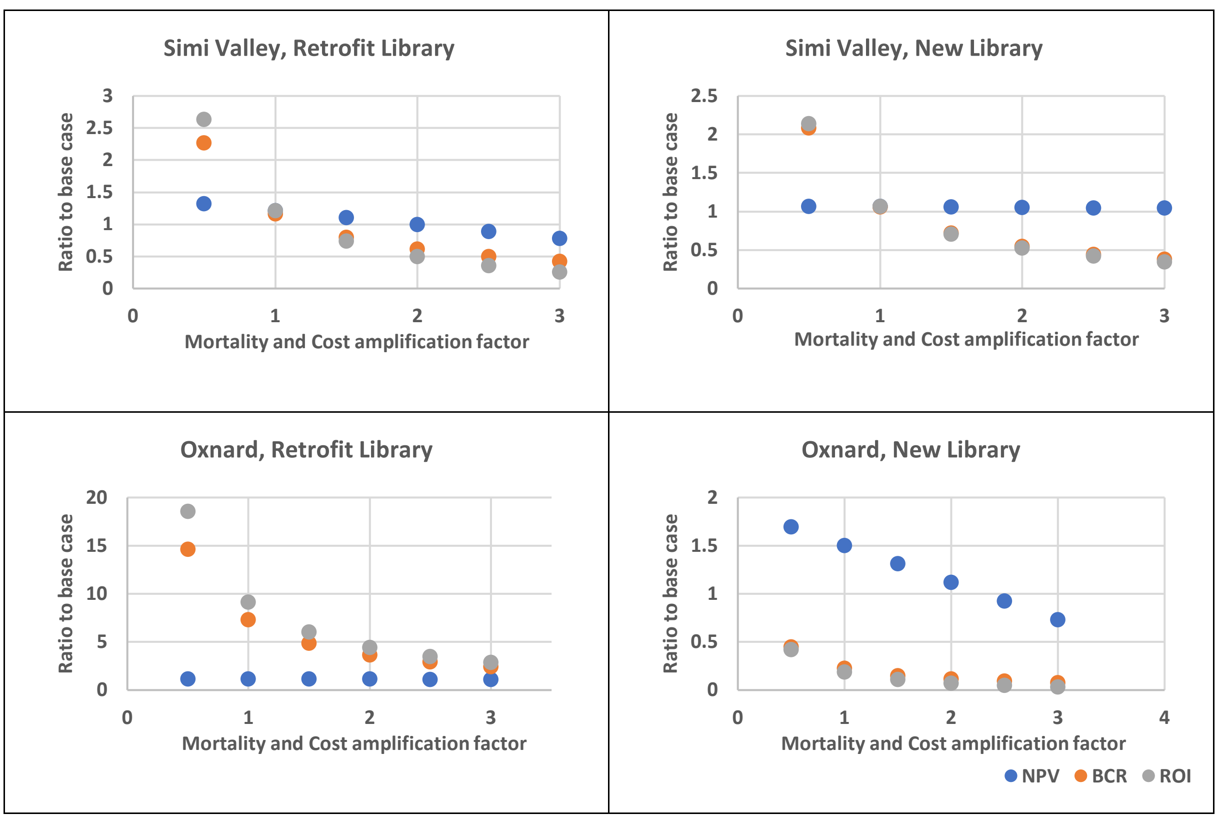

Figure 2. Mortality and Cost amplification effect on key EDGe$ analysis outputs

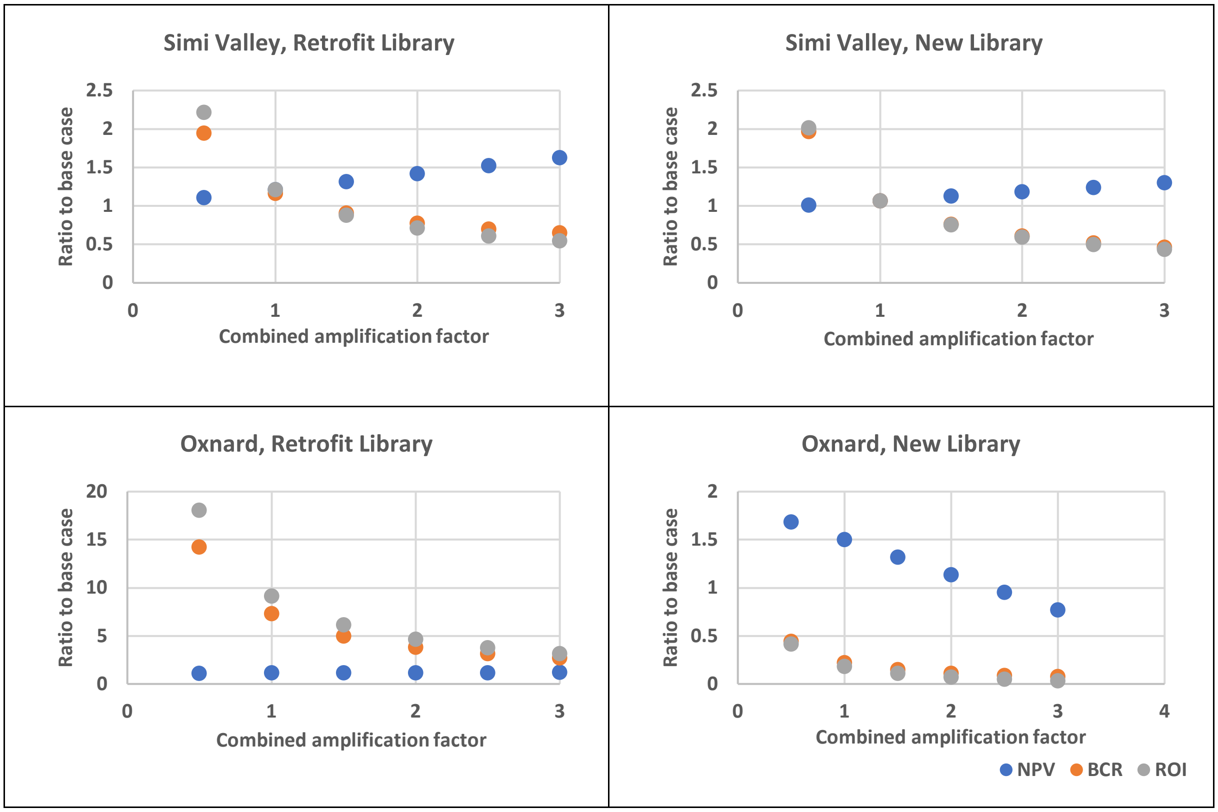

Figure 3. Combined amplification effect on key EDGe$ analysis outputs

The effects are mostly mixed, depending on the ratio of costs, loss, loss reduction benefits, other benefits, or mortality expectations, which each community perspective and development option assumed. In some cases, due to development options having loss reduction as a benefit, loss amplification led to a greater NPV, resulting in a development option becoming more desirable for the communities. In other cases, the estimated material losses, costs, and loss of life dominated and the loss amplification resulted in a lower NPV. The mixed effect underscores the need for some levels of demand surge/loss amplification to be accounted for in economic models. The net effect of such amplification on planning is difficult to predict without performing these computations, and the added knowledge may affect a community's decision making to more accurately account for demand surges and increased losses or replacement costs during a real disaster reconstruction effort.

4. Risk Aversion Analysis

4.1. Different Risk Aversion Levels

Different levels of diminishing marginal utility, which translate into different risk aversion levels are plotted below (see Figure 4) by adjusting the a parameter in the CRRA utility equation (see equation 4). The levels of risk aversion/diminishing marginal utility tested are $a = \{2, 5, 10, 20\}$. The greater the a parameter, the less risk-averse the entity with the corresponding utility curve will be. For a visualization of the effect of these parameter levels on marginal utility, the utility curve is plotted at Figure 4 for each risk aversion level with a payout ranging from \$ 0 to \$ 100 in increments of \$ 10. The utility function translates the payouts into a dimensionless representation of utility units. The utility of a \$10 payout at different risk aversion levels has a coefficient of variation of 14% (6.3, 7.9, 8.8, 9.4). However, the utility of a \$ 100 payout varies more across the different levels of risk-averse entities, with a coefficient of variation of 43% (20, 49.8, 70.1, 83.6).

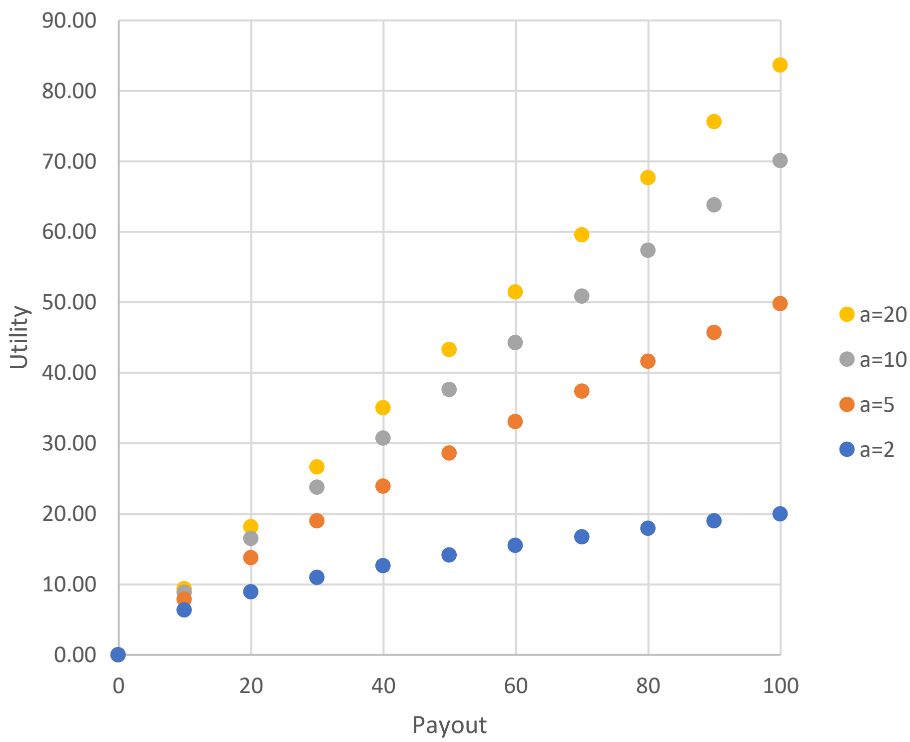

Figure 4. Sample utility curves at different risk aversion levels.

For a further demonstration of the meaning of these different risk levels, we can consider the effect each will have on the expected utility and certainty equivalent of a coin toss (50 % chance of each outcome) bet to win \$ 100 or win \$ 0. The certainty equivalent of each risk aversion level can be computed. This is once again the equivalent amount of payout a risk-averse entity would accept as equivalent to the uncertain bet with an expected payout of \$50. The general process is graphically represented in Figure 5. The results are shown in Table 38.

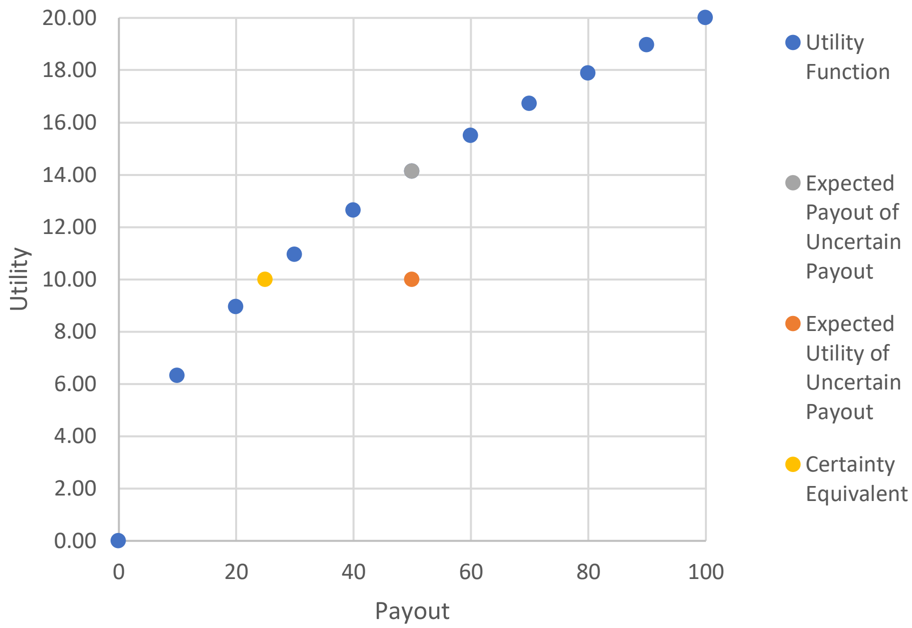

Figure 5. Certainty Equivalent computation at $a = 2$ risk aversion level for a demonstration bet

Table **37.** Certainty equivalent and risk premium computations for a demonstration bet at different risk aversion levels

	$a = 2$	$a = 5$	$a = 10$	$a = 20$
Expected Utility of Expected Payout	14.10	28.60	37.60	43.30
Expected Utility of Uncertain Payout	10.00	24.90	35.10	41.80
Certainty Equivalent	\$ 25.00	\$ 42.04	\$ 46.29	\$ 48.21
Risk Premium	\$ 25.00	\$ 7.96	\$ 3.71	\$ 1.79
Risk Premium (proportional)	100.0 %	18.9 %	8.0 %	3.7 %

The parameter a greatly influences the certainty equivalent that the entity would consider equivalent to the bet. At $a = 2$ an entity would accept a \$ 25.00 payout as equivalent to the uncertainty of the bet, even though the expected payout is \$ 50.00. At less risk-averse levels, for example at $a = 20$ the entity would accept \$ 48.21 to avoid the bet, much closer to the expected payout.

4.2. Impact On Case Study for Different Risk Aversion Levels

Risk aversion cases require uncertainty, and EDGe\$ can assume uncertainty for most inputs. Assuming a Gaussian (normal) distribution for all data items with a standard deviation of 50% of the mean, except for mortality.[1] The resulting 95% confidence interval of the final BCA, NPV

[1] Note that the EDGe\$ Online Tool does not currently have uncertainty in the category of mortality implemented.

was then estimated as a discrete uncertainty distribution with an 80% chance of the mean occurring and a 10% chance of each outer bound interval occurring. Simulation data could ultimately be used to compute a more precise uncertainty distribution of the NPV and eliminate this discrete estimation step.

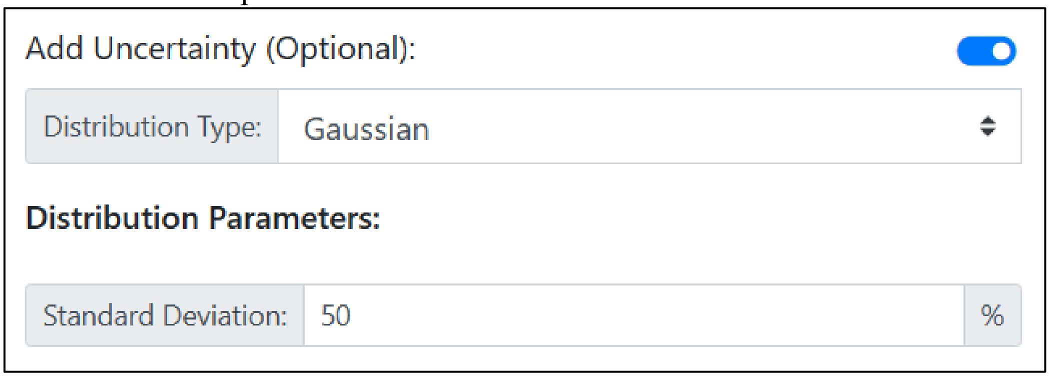

Figure 6. Sample of EDGe$ interface for uncertainty input, where standard deviation is expressed as a percentage of the mean, or coefficient of variation.

For the WUI case study, the certainty equivalents and risk premium are computed for each community perspective and development option, and for each risk aversion level, assuming the NPV and its upper and lower bounds with uncertainty are the expected payouts. The discrete uncertainty payoff estimates are shown in Table 38. The outputs of the utility and risk aversion computations are shown in Tables 39-43.

Table 38. Discrete distribution of NPV (payout) and expected payout from uncertainties input into EDGe$ for each community perspective and development option

	80 % (mean)	10.0 % (lower bound)	10.0 % (upper bound)	Expected Payout
Simi Valley Retrofit	$ 45 332 970	$ 41 889 980	$ 48 646 420	$ 45 320 016
Simi Valley New Library	$ 238 591 050	$ 238 274 780	$ 238 910 140	$ 238 591 332
Oxnard Retrofit	$ 42 455 000	$ 42 194 090	$ 42 711 510	$ 42 454 560
Oxnard New Library	$ 337 685 790	$ 333 256 820	$ 342 468 370	$ 337 721 151

Table 39. Certainty equivalent and risk premium computations for Simi Valley perspective, retrofit option at different risk aversion levels

	$a = 2$	$a = 5$	$a = 10$	$a = 20$
Expected Utility of Expected Payout	13464.0	1667024.8	8638106.2	19758407.9
Expected Utility of Uncertain Payout	13462.2	1666876.2	8637673.1	19757885.1
Certainty Equivalent	$ 45 307 379	$ 45 314 965	$ 45 317 491	$ 45 318 754
Risk Premium	$ 12 637.33	$ 5 050.89	$ 2 524.79	$ 1 262.23
Risk Premium (proportional)	0.0279 %	0.0111 %	0.0056 %	0.0028 %

Table 40. Certainty equivalent and risk premium computations for Simi Valley perspective, new library option at different risk aversion levels

	$a = 2$	$a = 5$	$a = 10$	$a = 20$
Expected Utility of Expected Payout	30892.8	6295550.9	38516488.5	95730058.3
Expected Utility of Uncertain Payout	30892.8	6295550.8	38516487.9	95730057.5
Certainty Equivalent	$ 8 591 311	$ 38 591 324	$ 38 591 328	$ 38 591 330
Risk Premium	$ 21.15	$ 8.46	$ 4.23	$ 2.11
Risk Premium (proportional)	0.0000089 %	0.0000035 %	0.0000018 %	0.0000009 %

Table 41. Certainty equivalent and risk premium computations for Oxnard perspective, retrofit option at different risk aversion levels

	$a = 2$	$a = 5$	$a = 10$	$a = 20$
Expected Utility of Expected Payout	13031.4	1582156.7	8144968.3	18569684.4
Expected Utility of Uncertain Payout	13031.4	1582155.7	8144965.6	18569681.1
Certainty Equivalent	$ 2 454 481	$ 42 454 528	$ 42 454 544	$ 42 454 552
Risk Premium	$ 78.84	$ 31.53	$ 15.77	$ 7.88
Risk Premium (proportional)	0.0001857 %	0.0000743 %	0.0000371 %	0.0000186 %

Table 42. Certainty equivalent and risk premium computations for Oxnard perspective, new library option at different risk aversion levels

	$a = 2$	$a = 5$	$a = 10$	$a = 20$
Expected Utility of Expected Payout	36754.4	8312977.8	52657462.3	133170105.1
Expected Utility of Uncertain Payout	36754.2	8312953.1	52657374.1	133169987.3
Certainty Equivalent	$ 337 718 008	$ 337 719 894	$ 337 720 522	$ 337 720 837
Risk Premium	$ 3 142.54	$ 1 257.15	$ 628.60	$ 314.31
Risk Premium (proportional)	0.0009305 %	0.0003722 %	0.0001861 %	0.0000931 %

Generally, and for our specific case study, greater risk aversion levels reduced the attractiveness of the development options with greater uncertainty. This effect is best observed in the risk premium measure, which is the difference between the certainty equivalent and their expected payout (i.e., NPV). The risk premium of development options with very small uncertainty, for example Simi Valley's new library option, is quite small on the order of $20 or less. The small uncertainty of this option is due to the dominance of loss of life, which does not have uncertainty associated with it. The risk premium of a more uncertain development option, such as Simi Valley's Retrofit option, is on the order of $1000- $10 000.

The different levels of risk aversion greatly affect the risk premiums of each community. For example, the difference between the risk premium for $a = 2$ and $a = 20$ level risk aversion is almost precisely an order of magnitude for all development options and community perspectives. A wide range of risk aversion was trialed in this case study to demonstrate the different effects of each. Some entities may be able to tolerate more uncertainty in exchange for a better expected outcome, and an appropriate level of risk aversion should be chosen to reflect that. Ultimately, a risk aversion level for each specific community or entity would need to be determined through some form of survey or other method of inquiry.

In each of our case studies, the level of uncertainty was relatively low, and for some it was extremely low. Correspondingly, the proportional risk premiums for each option were low or negligible. They were below 0.1 % for all development options and community perspectives, and in some cases much lower. This effect highlights that in cases where uncertainties are small, risk aversion effects will also be relatively low. In some cases, mortality and loss of life were a large influence on the overall BCA and uncertainty could not be assumed for these values in a reasonable way, or in the current EDGe$ implementation.

If uncertainties of the development options were larger, or vastly different, then the consideration of risk aversion would be impactful. As in the extreme coin toss bet example, the parameters of the utility function of an entity and therefore their risk aversion can have extreme effects on the desirability of an uncertain outcome. At the most risk-averse level the coin toss bet, which is perhaps the most extreme example of uncertainty, resulted in a 100 % risk premium. The lowest level of risk aversion trialed resulted in a 3.7 % risk premium.

5. Implications

Benefit-cost analysis is widely used for planning by communities and other entities that compares benefits, costs, and externalities, and helps ensure funds are spent most effectively. A BCA offers an objective, quantitative method for community leaders to weigh different choices that can have broad effects on the public they serve, including loss of life and exposure to disaster risk. The efficiency of the allocation of limited resources is improved through a BCA by helping ensure choices are made that maximize the net present value of benefits relative to the costs to the community.

Standard BCA analysis can have limitations. In an extreme event, such as an extreme weather or climate-associated event, the static assumptions of a BCA might not hold. Demand surges during natural disasters and other large-scale events occur in chaotic conditions that can cause costs and losses to far exceed planned monetary values. A static BCA analysis also struggles to account for the uncertainty of outcomes, causing estimates without uncertainty to potentially underestimate or overestimate actual outcomes. When uncertainty is accounted for, as EDGe$ is capable of, the ability of a community to handle the worst-case outcomes for a decision with large uncertainty may not be acceptable even if that decision leads to the best statistically expected outcome.

Accounting for disaster related demand surge with loss amplification and uncertainty with risk aversion are two potential improvements to the standard BCA processes that can account for these real-world challenges and potential pitfalls. Loss amplification approaches use historical data for demand surges and replacement costs during disasters to add relevant multiplication factors to planned losses potentially incurred during such a disaster. Utility based risk aversion can characterize a community's appetite for risk and weigh uncertain outcomes, producing certainty equivalent net present value measures that can be used to quantitatively compare outcomes with different uncertainty levels. These promising additions to BCA are envisioned to address several challenges for BCA use at the community level, and thereby enhance community resilience performance.

6. Discussion and Future Research

The use of BCAs in practice is continuously evolving as new methods and analysis tools are developed and enhanced, such as with EDGe$. Some of parallel developments have been called "dynamic" BCAs, which also account for uncertainties and risk ambiguity, focus on tradeoffs, and aim to integrate new information or lessons learned from prior endeavors into future analysis [30]. Integrating some of those techniques with our analysis could prove promising to enhance the accuracy of BCAs for projects with long time horizons, disaster risk, or uncertain future conditions.

Demand surge modeling has so far been characterized by the study of prior disasters or high impact events, including pandemics, and the recovery efforts and costs that have been associated with them. Limited scholarly work on this topic has been published, and published work often focuses on either labor or material costs [29, 31]. Improvements to the modeling of these disaster recovery efforts and research to predict and assign loss amplification factors for disasters that have not yet occurred could prove critical to their implementation in a forward-looking BCA. Investigations into and pursuit of supply chain management practices and emergency stockpiling efforts could minimize the actual demand surge effects and could form a basis for communities to mitigate demand surge's deleterious effects on planning. Modeling of demand surge and loss amplification could form a basis for quantifying the benefits of stockpiling and supply chain management.

Risk aversion and the diminishing marginal utility of monetary payouts are well documented decision-making factors that affect the way communities, large organizations, and even individuals make decisions. Although the WUI case study example possessed much smaller uncertainty ranges than many projects likely will, it still did show that different levels of risk aversion affected the desirability of each outcome. Projects with larger associated uncertainties are expected to benefit more from the consideration of risk aversion. Pinpointing exactly the correct levels of risk aversion that a community or entity possesses remains a challenge; however, it is not easily answered without detailed insight into their decision making. Further study into the methods that could be utilized to determine the level of risk aversion for a community or other entity could provide the link needed to integrate the methods for risk aversion into BCAs in practice. In addition, further factors that influence risk-taking beyond expected utility theory, such as psychological or behavioral factors, including loss aversion and prospect theory, could be explored to enhance the behavior modeling of risk-averse communities and other entities [32]. There are differences in response to the known uncertainties in a potential budget versus the ambiguity in probability of events as well as differences in perception of gains and losses.

References

[1] Helgeson, J. F., and P. J. Zhang. (2020) Economic Decision Guide Software (EDGe: Wildfire Urban Interface (WUI) case study. NIST SP 1260. Gaithersburg, MD: National Institute of Standards and Technology.Giancoli DC (2008) *Physics for scientists and engineers with modern physics* (Pearson Education, Upper Saddle River, N.J.), 4th Ed.
[2] Gilbert, S. W., Butry, D. T., Helgeson, J. F., & Chapman, R. E. (2015). Community resilience economic decision guide for buildings and infrastructure systems. NIST special publication, 1197.
[3] Gilbert, S., and Ayyub, B., (2016) "Models for the Economics of Resilience," ASCE-ASME J. Risk Uncertainty Eng. Syst., Part A: Civil Eng., https://doi.org/10.1061/AJRUA6.0000867
[4] Community Resilience Group. (2016). Community resilience planning guide for buildings and infrastructure systems: Volume I (NIST SP 1190v1). National Institute of Standards and Technology. https://doi.org/10.6028/NIST.SP.1190v1
[5] Kind, J., Wouter Botzen, W. j., & Aerts, J. C. J. H. (2017). Accounting for risk aversion, income distribution and social welfare in cost-benefit analysis for flood risk management. WIREs Climate Change, 8(2), e446. https://doi.org/10.1002/wcc.446
[6] Hallegatte, S. (2006). A Cost-Benefit Analysis of the New Orleans Flood Protection System. AEI-Brookings Joint Center. Regulatory Analysis, 06–02.
[7] Bruce, J. P. (1994) "Natural Disaster Reduction and Global Change." Bull. Am. Meteorol. Soc., 75 (10): 1831–1835. American Meteorological Society.
[8] Smith, A. B. (2020) "U.S. Billion-dollar Weather and Climate Disasters, 1980 - present (NCEI Accession 0209268)." NOAA National Centers for Environmental Information.
[9] Cutter, S. L., L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate, and J. Webb. (2008) "A place-based model for understanding community resilience to natural disasters." Glob. Environ. Change, Local evidence on vulnerabilities and adaptations to global environmental change, 18 (4): 598–606. https://doi.org/10.1016/j.gloenvcha.2008.07.013.
[10] Mohleji, S., and R. Pielke. (2014) "Reconciliation of Trends in Global and Regional Economic Losses from Weather Events: 1980–2008." Nat. Hazards Rev., 15 (4): 04014009. American Society of Civil Engineers. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000141.
[11] Radeloff, V. C., D. P. Helmers, H. A. Kramer, M. H. Mockrin, P. M. Alexandre, A. Bar-Massada, V. Butsic, T. J. Hawbaker, S. Martinuzzi, A. D. Syphard, and S. I. Stewart. (2018) "Rapid growth of the U.S. wildland-urban interface raises wildfire risk." Proc. Natl. Acad. Sci., 115 (13): 3314–3319. Proceedings of the National Academy of Sciences. https://doi.org/10.1073/pnas.1718850115.
[12] Olsen, A. H., and K. A. Porter. (2011) "What We Know about Demand Surge: Brief Summary." Nat. Hazards Rev., 12 (2): 62–71. American Society of Civil Engineers. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000028.
[13] Ayyub, B.M. (2014). Risk Analysis in Engineering and Economics, Second Edition, CRC Press, Taylor & Francis, FL.
[14] Kniesner, T. J., & Viscusi, W. K. (2019). The Value of a Statistical Life (SSRN Scholarly Paper 3379967). https://doi.org/10.2139/ssrn.3379967
[15] Viscusi, W. K., & Aldy, J. E. (2003). The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World. Journal of Risk and Uncertainty, 27(1), 5–76. https://doi.org/10.1023/A:1025598106257

[16] Viscusi, W. K. (2010). The heterogeneity of the value of statistical life: Introduction and overview. Journal of Risk and Uncertainty, 40(1), 1–13. https://doi.org/10.1007/s11166-009-9083-z
[17] Ahmadi, N., and S. M. Shahandashti. (2018) "Role of Predisaster Construction Market Conditions in Influencing Postdisaster Demand Surge." Nat. Hazards Rev., 19 (3): 04018010. American Society of Civil Engineers. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000296.
[18] Arora, H., T. S. Raghu, and A. Vinze. (2010) "Resource allocation for demand surge mitigation during disaster response." Decis. Support Syst., 50 (1): 304–315. https://doi.org/10.1016/j.dss.2010.08.032.
[19] Olsen, A. H., and K. A. Porter. (2013) "Storm Surge to Demand Surge: Exploratory Study of Hurricanes, Labor Wages, and Material Prices." Nat. Hazards Rev., 14 (4): 247–257. American Society of Civil Engineers. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000111.
[20] Pradhan, S., and E. Arneson. (2021) "Postdisaster Labor-Demand Surge in the U.S. Highways, Roads, and Bridges Construction Sector." J. Manag. Eng., 37 (1): 04020102. American Society of Civil Engineers. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000869.
[21] Eash-Gates, P., M. M. Klemun, G. Kavlak, J. McNerney, J. Buongiorno, and J. E. Trancik. (2020) "Sources of Cost Overrun in Nuclear Power Plant Construction Call for a New Approach to Engineering Design." Joule, 4 (11): 2348–2373. https://doi.org/10.1016/j.joule.2020.10.001.
[22] Friedman, M., and L. J. Savage. (1952) "The Expected-Utility Hypothesis and the Measurability of Utility." J. Polit. Econ., 60 (6): 463–474. The University of Chicago Press. https://doi.org/10.1086/257308.
[23] Arrow, K. J. (1965) Aspects of the theory of risk-bearing. Yrjö Jahnssonin Säätiö.
[24] Pratt, J. W. (1964) "Risk Aversion in the Small and in the Large." Econometrica, 32 (1/2): 122–136. [Wiley, Econometric Society]. https://doi.org/10.2307/1913738.
[25] Cal Fire. (2020) "California Fire Hazard Severity Zone Viewer." Calif. State Geoportal. https://gis.data.ca.gov/datasets/789d5286736248f69c4515c04f58f414.
[26] Miller, J. D., and H. Safford. (2012) "Trends in Wildfire Severity: 1984 to 2010 in the Sierra Nevada, Modoc Plateau, and Southern Cascades, California, USA." Fire Ecol., 8 (3): 41–57. SpringerOpen. https://doi.org/10.4996/fireecology.0803041.
[27] Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. (2006) "Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity." Science, 313 (5789): 940–943. American Association for the Advancement of Science. https://doi.org/10.1126/science.1128834.
[28] Office of Management and Budget. (2003) "Circular A-4." White House. Accessed September 13, 2023. https://obamawhitehouse.archives.gov/node/15644.
[29] Döhrmann, D., M. Gürtler, and M. Hibbeln. (2013) "An econometric analysis of the demand surge effect." ZVersWiss, 102 (5): 537–553. https://doi.org/10.1007/s12297-013-0239-1.
[30] Dudley, S. E., Pérez, D. R., Mannix, B. F., & Carrigan, C. (2019). Dynamic Benefit-Cost Analysis for Uncertain Futures. Journal of Benefit-Cost Analysis, 10(2), 206–225. https://doi.org/10.1017/bca.2019.13
[31] Hallegatte, S., and V. Przyluski. (2010) "The Economics of Natural Disasters: Concepts and Methods." SSRN Scholarly Paper. Rochester, NY.

[32] Kahneman, D., and A. Tversky. (1979) “Prospect Theory: An Analysis of Decision under Risk.” Econometrica, 47 (2): 263–291. [Wiley, Econometric Society]. https://doi.org/10.2307/1914185.

Appendix A. List of Symbols, Abbreviations, and Acronyms

BCA

benefit-cost analysis

BCR

benefit to cost ratio

CE

certainty equivalent

CRRA

constant relative risk aversion

EDGe$

Economic Decisions Guide Software

HARA

hyperbolic absolute risk aversion

NPV

net present value

OMR

operation, repairs, and management

ROI

return on investment

RP

risk premium

RRPL

Ronald Reagan Presidential Library

R&R

response and recovery

WUI

wildland-urban interface