NIST Special Publication 1214

The Economic Decision Guide Software (EDGeS) Tool

User Guidance

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Abstract

The EDGeS (Economic Decision Guide Software) Tool version 1.0 implements a rational, systemic methodology for selecting cost-effective community resilience alternative strategies.

The methodology is based on guidance provided in the NIST "Community Resilience Economic Decision Guide for Buildings and Infrastructure Systems" (*Economic Decision Guide*). The decision support software is aimed at those engaged in community-level resilience planning, such as community planners, and resilience officers, as well as budget officers. It provides a standard economic methodology for evaluating investment decisions aimed to improve the ability of communities to adapt to, withstand, and quickly recover from disruptive events.

EDGeS is designed for use in conjunction with the NIST "Community Resilience Planning Guide for Buildings and Infrastructure Systems" (CRPG). The methodology used in this software decision support tool frames the economic decision process by identifying and comparing the relevant present and future streams of costs and benefits—the latter realized through cost savings and damage loss avoidance—associated with new capital investment into resilience to those future streams generated by maintaining a community's status-quo.

This methodological approach aims to enable the built environment to be utilized more efficiently in terms of loss reductions during recovery and to enable faster and more efficient recovery in the face of future disruptions. It encourages users to consider non-disaster related benefits (co-benefits and co-costs) of resilience planning. Topics related to non-market values and uncertainty are also included.

The methods employed are based on best practices in building economics and the economics of community resilience planning. EDGeS is meant to be practical, flexible, and transparent, as the methodological approach can be applied across a wide range of community types and project types.

Keywords: Benefit-cost analysis; buildings; communities; constructed facilities; resilience; economic analysis; economic decision tool; life-cycle costing; resilience dividend; software

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List of Acronyms

AEO	Applied Economics Office
ARI	Annual Return on Investment
BCA	Benefit Cost Analysis
BCR	Benefit Cost Ratio
COV	Coefficient of Variation
CPT	Collaborative Planning Team
CRPG	Community Resilience Planning Guide
DHS	Department of Homeland Security
EDG	Economic Decision Guide
EDGeS	Economic Decision Guide Software
EL	Engineering Laboratory
IRR	Internal Rate of Return
NIST	National Institute of Standards and Technology
NPV	Net Present Value
OMR	Operation, Maintenance, and Repair
PPD	Presidential Policy Directive
ROI	Return on Investment
SDR	Subcommittee on Disaster Reduction
SIR	Savings to Investment Ratio
SROI	Social Return on Investment
USD	United States Dollars

1 Introduction

1.1 Background

Communities need practical metrics, data, and tools to support decisions related to community resilience planning. The Engineering Laboratory (EL) of the National Institute of Standards and Technology (NIST) has addressed this high priority national need by extending its research to encompass research on resilience planning at the community-scale.

The NIST Community Resilience Planning Guide (CRPG) (2015) encourages communities to fold the concept of resilience into other community goals and plans (e.g., community business plans and disaster preparedness plans) (NIST 2016). The six-step process in the CRPG (2015) (Figure 1.1) describes how a community may plan for resilience, especially considering the entire community perspective. The convening idea is that a given community should look at their long-term goals and current gaps in infrastructure in a hazard-neutral manner. The community, through a collaborative planning team (CPT), then addresses the specific disasters to which that community is vulnerable.

The CRPG suggests six steps, of which the NIST Economic Decision Guide (EDG) is designed to help with the fourth. Step Four in the CRPG is *plan development*. During this step, there needs to be a way for the community to decide among competing community resilience plans. The NIST Economic Decision Guide (EDG) approach addresses this need, as illustrated in Figure 1.1. The seven-step process described in the EDG is noted in the left side of Figure 1.1. The goal is to determine in a standard manner the plan or combination of plans that yield the greatest net-benefit to the community.

Economic approaches and methods for cost estimation that consider the community level, opposed to valuation for a single structure, are relatively new. The EDG seven-step process allows communities to take a standardized approach that can be customized for their specific needs and circumstances. The EDGeS (Economic Decision Guide Software) Tool, referred to as EDGeS for the remainder of the document, was developed to facilitate communities' use of the process and to automatically provide key economic indicators arising from a benefit-cost analysis (BCA) to the user based on their inputs.

1.2 Purpose and Scope

The new idea is to address the economics of resilience planning in a holistic, integrated manner that encourages consideration of complex interactions between and among community systems that support the built environment.

The Applied Economics Office (AEO) of the NIST EL has addressed the need for standard and straight-forward ways to compare among identified potential resilience planning alternative projects. This process is overviewed in the NIST EDG (Gilbert et al. 2016). EDGeS makes the process of determining net-benefits from potential community resilience plans straightforward by walking the user through the process. It acts as an advanced calculator which takes user inputs and determines key economic values, which in turn facilitate the community's decision among alternative resilience plans.

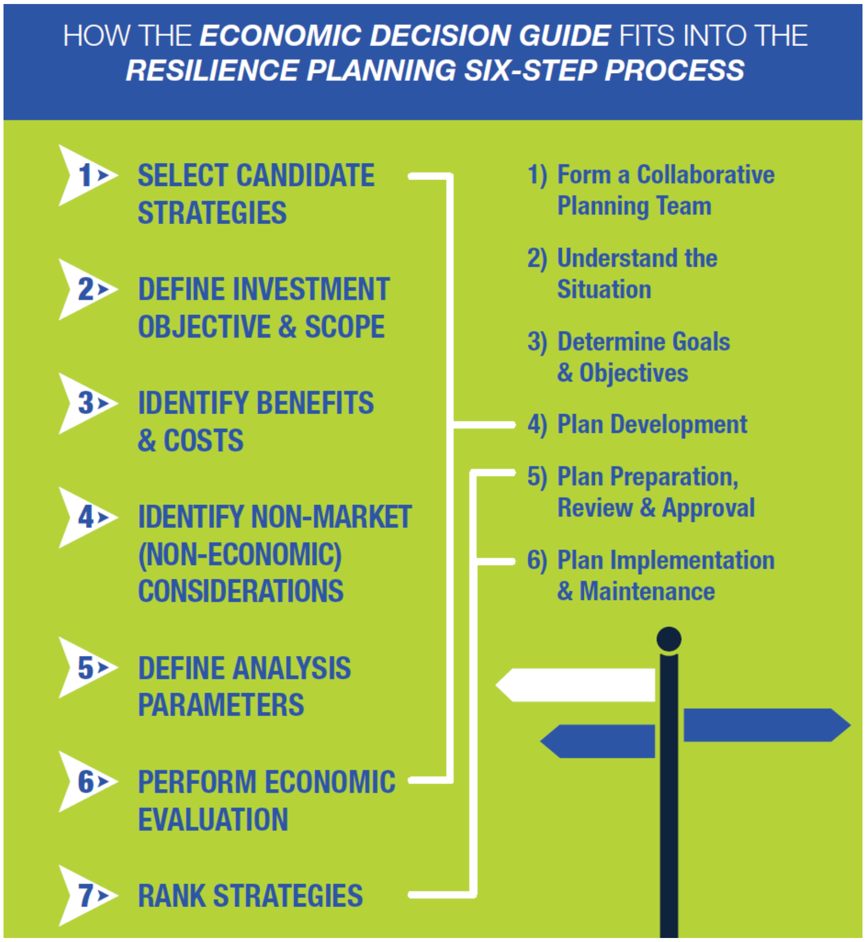

Figure 1.1 Steps of the EDG (left) as they fit within the steps of the CRPG (right)

EDGeS seeks to provide a mechanism to evaluate the efficiency of potential resilience plans and to prioritize them. It frames the economic decision process by identifying and comparing resilience-related costs and benefits, both across competing resilience plans and versus the status quo (i.e., business-as-usual) situation.

EDGeS encourages users to include avoided losses as part of the BCA. It also encourages the user to consider net co-benefits of resilience planning (e.g., see Fung and Helgeson 2017). In other words, EDGeS allows benefits (and costs) that are not contingent on occurrence of a disaster to be considered.

Overall, EDGeS offers a method that is transparent and standardized among different types of communities and various types of community resilience projects. At a high-level, the main difference between EDGeS and many other economics-related tools related to resilience planning is that EDGeS can be easily adapted across resilience project types and can deal with projects that involve multiple systems and/or interactions from a single sector project with other sectors (opposed to looking at projects from the point of view of a single sector devoid of external interactions). EDGeS offers a structured approach while allowing flexibility and encouraging consideration of complex interactions between and among community systems that support the built environment.

The major capabilities that EDGeS allows include the following:

1. Generalizability across broad, but meaningful, categories of costs and benefits.
2. Inclusion of co-benefits and co-costs in the user input and resulting analysis.
3. Inclusion of (positive and negative) externalities and the ability to assign these externalities.
4. Inclusion of user-defined uncertainty for each individual cost and benefit, as well as the analysis parameters, if desired by the user.
5. Ability for all data to be user-defined. There are some suggested values (e.g., value of a statistical life); however, this is easily changed or precluded by the user.
6. Ability to input data through the software screens or a specialized template spreadsheet.

EDGeS version 1.0 is a beta version tool that is currently under limited testing.

1.3 Organization of this Manual

This report contains six chapters and three appendices in addition to the Introduction; it is designed to walk the user through the features of EDGeS version 1.0 in a step-by-step fashion. Background material is first presented to make sure the user has a firm grounding in the concepts that underlie the software tool's framework. Specialized analysis features are then introduced that build on and reinforce each other. Throughout this User's Manual the objective is to teach the user how to use EDGeS and to gain a deeper understanding of the AEO's structured approach to the selection of cost-effective community resilience projects for dealing with natural and human-made hazards.

Chapter 2 covers the key concepts underlying EDGeS. Topics covered include an overview of the seven-step EDG process and the types of economic decisions and economic evaluation indicators available to decision makers. The chapter discusses the process by which the baseline analyses are constructed. The baseline analysis is the starting point for conducting an economic evaluation. In the baseline analysis, all data elements entered into the calculations are fixed. Chapter 2 also provides a brief introductory discussion of the treatment of uncertainty. Specifically, there is discussion of the importance of looking at uncertainty surrounding point estimates when possible. The concept of Monte Carlo simulations is introduced.

Chapter 3 introduces the case studies offered by researchers in the AEO to help users learn to use EDGeS. The Riverbend, USA case study is introduced in great detail, as it will be used throughout the remainder of the User Manual to demonstrate and explain key software features. Three additional case studies are introduced, which are further explained in Appendix B. Example Scenarios.

Chapter 4 describes how the user can get started with using EDGeS.

Chapter 5 describes user inputs to the software that enable the comparison among user-defined alternative resilience plans. Input screens that do not allow the user to define uncertainty around point estimates are dealt with in this chapter.

Chapter 6 provides an overview of the treatment of uncertainty in economic analyses.

Chapter 7 describes EDGeS input screens and user inputs when there is data available about the uncertainty around the fixed-point estimates for costs and benefits for a candidate project or candidate projects.

Chapter 8 describes analysis outputs by EDGeS. It also addresses the formats in which this data can be exported by the user for use in further analyses or in presentations to other community stakeholders.

There are three extensive appendices in the User Guide:

> Appendix A provides a detailed tutorial for the user, based on the Riverbend case study.
>
> Appendix B provides further details of the resilience project economic analysis examples presented in Chapter 2. These examples can be used by the user to practice using EDGeS.
>
> Appendix C offers guidance on the use of a spreadsheet template for inputting data into EDGeS without interacting with the input guidance screens.

2 Key Concepts

2.1 Overview of the EDG 7-Step Protocol

Creating increased resilience in the built environment and associated systems (e.g., social and economic) against extreme events, such as fires, floods, earthquakes, and other natural and human-made hazards is a constant challenge for communities.[1]

The National Research Council (2012) defines resilience as "the ability to prepare and plan for, absorb, recover from or more successfully adapt to actual or potential adverse events." This definition is consistent with U.S. government agency definitions (SDR 2005; DHS 2008; PPD- 8 2011). Presidential Policy Directive 8 (PPD-8 2011) defines resilience as "the ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies." Presidential Policy Directive 21 (PPD-21 2013) on Critical Infrastructure Security and Resilience expanded the definition to include the "ability to prepare for and adapt to changing conditions and to withstand and recover rapidly from disruptions." Further it states, "resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."

A critical part of improving community-level resilience is acknowledging and prioritizing actions or projects for the buildings and infrastructure systems that support important social functions. A given community may assess the hazards it most readily faces and in turn prepare, mitigate risk, and plan recovery narrowly tailored to this assessment. However, it is also important to assess community goals in a broader, perhaps hazard agnostic, setting, as well, and ensure that these goals are addressed while planning for increased resilience.

Often resilience goals may be achieved through one of a suite of project options or via a combination of projects. Thus, it is important to employ a process by which to assess the efficiency of such projects in meeting the community's resilience goals.

The seven-step process laid out in the EDG and which is used in EDGeS is presented in Figure 2.1.

[1] The term *community* can be defined in various ways on the local and national scales. This report considers communities to refer to "a place designated by geographical boundaries that function under the jurisdiction of a governance structure" (e.g., town, city, county) (NIST 2016).

Figure 2.1 Steps in the EDG and inputs to EDGeS.

In Figure, 2.1, Steps 1 to 5 account for user inputs to EDGeS that the user may arrive at through use of the EDG. EDGeS conducts Step 6 for the user and provides outputs to support the user in her interpretation of results.

1. **Select candidate strategies** for increased community resilience based on existing studies, computer modeling, and expert judgment.

2. **Define economic objectives** expected to provide the greatest net-benefit accounting for all factors that can be valued**.** A community will want to decide what additional factors, such as increased access to a quality livelihood, education, and other social welfare resources, are important in choosing between and among alternative strategies. Furthermore, communities may choose a diverse approach to resilience planning that involves specific mitigation actions to reduce risk and steps to transfer risk, such as insurance investments. In this step, communities should identify a time frame for the analysis – the period over which alternatives are compared in terms of costs and benefits that occur. Political, legal, financial,

and other considerations will influence which resilience projects a community can undertake, and can be hard to quantify. Nevertheless, it is vital to factor them into planning. Planners also often will need to consider ways to reformulate plans or phase-in constituent activities for a given plan over time. This may be because of monetary constraints, but may also be the product of social constraints identified by the community.

3. **Identify benefits and costs** associated with each candidate resilience plan. Benefits are determined primarily based on the improvement in performance over the status quo for a hazard event. That includes reductions in the magnitude of damages (e.g., to property and livelihoods) from a disaster as well as lower costs during the response and recovery phases. Benefits also include the positive effects, or co-benefits, from a resilience strategy that improves community function and value even when a hazard event has not occurred.

   Costs to implement a mitigation strategy may occur once or multiple times over a project's life. In addition to initial costs, estimates should include all costs associated with owning, operating, maintaining, and disposing of goods and services related to the project. Non-economic costs, like environmental degradation due to construction, and social disruption due to displacement of a neighborhood or vulnerable population, should also be considered.

   Costs or benefits that impact a third party that is not part of the direct decision to implement a given strategy, termed externalities, should be identified. Externalities may be positive or negative. Externalities may also be 'non-market' in nature, meaning they are not bought or sold in the market, so their price is not observable; in this case, they should be considered under step 4.

4. **Identify non-market considerations**. Externalities and other impacts may or may not be quantifiable. Residents of homes near a transportation project that is part of a resilience plan may suffer from noise, dust, degraded air quality or traffic restrictions during or after construction.

   Economists have several methods for determining and placing a value on this category of costs. They can be determined and considered as "contingent values," based on a survey of homeowners and prospective homeowners in the area, for example. While contingent valuation is based on direct or stated preferences, "hedonic valuation" is an indirect or revealed preference approach to non-market valuation. The EDG (2016) offers more options and details, but regardless of the method selected, it is important that communities put their own values on these non-market/non-economic considerations, which may or may not be captured as part of Step 3.

5. **Define analysis parameters** as they relate to the community's needs. Communities considering resilience options that require significant funding need to select a discount rate, which reflects the community's time preference for money in present-day terms. This decision is crucial in selecting candidate resilience strategies; as the time preference for money will affect affordability at a particular point in time. Discounting future consumption allows comparison between current and future consumption in equivalent terms. In this case, that means discounting future costs and benefits for the proposed mitigation strategies.

   If available, distributional assumptions help provide accurate estimates of expected costs and benefits associated with competing investment scenarios. Distributional assumptions for benefits—the expected reduction in losses should a disaster occur related to uncertainties related to disaster occurrence and outcome. Distributional assumptions for costs are due to typical uncertainties related to cost estimation, such as budgetary constraints. Others may be associated with dependence on the timing and severity of the disaster itself (e.g., response and recovery costs).

6. **Perform Economic Evaluation**. The EDG treats extreme hazard events as discrete, relatively rare events with significant long-term consequences. Still, the frequency and hazard level of multiple disruptive events clearly matter and should be factored into economic analysis.

   Several economic methods are available for evaluating investment decisions aimed to improve the ability of communities to adapt to, withstand, and quickly recover from disruptive events.

   - *Compute Present Expected Value*. This part of the analysis will answer the key question, "How do you value resilience strategies?"

   - *Alternative Formulations*. "Expected utility" is a popular economic strategy for choosing between alternative approaches when there is uncertainty in the potential outcomes. Friedman and Savage (1952) point out that decision-makers do not in fact calculate utilities before making every choice. But utility analysis is useful if decision-makers generally act as if they had compared expected utilities and as if they knew the odds for the economic choices being evaluated.

   - *Evaluate Impact of Uncertainty*. There are many uncertainties in estimating the present expected net benefits for a mitigation strategy outside of the uncertainty associated with whether or not a disaster will occur in a given time period. Examples include: timing and likelihood of future hazards, amount of damage a future hazard will cause, future costs of mitigation strategies, uncertainty about the validity of models used to estimate present expected net benefits, etc.

   Five economic evaluation criteria are available in EDGeS' output analysis, once the user has input all relevant data: 1. net present value (NPV), 2. benefit-to-cost ratio (BCR), 3. Return-on-investment (ROI), 4. non-disaster ROI, and 5. internal rate of return (IRR).

7. **Rank strategies** for implementation – after accounting for relative net benefits and considering constraints and non-market considerations, such as effects on social cohesion. The optimal choice is the combination of actions whose total cost is affordable and offers the greatest net benefit, in monetary and non-monetary terms.

2.2 Types of Community Resilience Economic Decisions

EDGeS was created explicitly with the goal of providing a general process that could apply to resilience projects at the community level across sector types and across community types.

Investment decisions associated with alternative resilience plans at the community level may include construction of a new set of buildings, changes in zoning, the renovation of an existing constructed facility (e.g., a bridge), or the modernization of an existing system.

Each of these types of resilience projects in turn involve relevant impacts on and effects from related systems. The seventh step in the EDG approach is to *rank strategies*; however, there are four basic types of investment decisions for which an economic analysis is appropriate and for which EDGeS may be employed:

1. Deciding whether to accept or reject a given alternative/project (Should the particular project alternative be undertaken in the first place?);
2. Identifying the most efficient alternative/project size/level, system, or design (How should a particular project alterative be configured/scaled?);
3. Identifying the optimal combination of interdependent projects (i.e., the right mix of sizes/levels, systems, and designs for a group of interdependent projects – How to choose the best combination of candidate projects?); and
4. Deciding how to prioritize or rank independent projects when the available budget cannot fund them all. Each type of investment decision is important. The aim is how to get the most impact for the given budget.

2.3 Input Types

This section overviews the types of data accepted by EDGeS and that are relevant to the economic analysis performed. The process of inputting the data into EDGeS and the associated input screens are described in Section 3.

2.3.1 Assessment Parameters

2.3.1.1 Hazard likelihood and magnitude

Defining the expected occurrence—timing and likelihood—of a hazard event is important in terms of understanding how resilience improvements will interact. These are important analysis parameters that affect the overall economic analysis.

The CRPG (2016) encourages communities to define three hazard levels for planning purposes: routine, design, and extreme. Any of these three levels may be incorporated into the EDGeS analysis.

- Routine hazard: A high-frequency/ low-consequence event. It is expected to occur more often than the design hazard, but result in a stress on the built environment below the design level causing little/no damage or disruptions.
- Design hazard: The level designed for in the codes and standards for buildings, bridges, and similar infrastructure systems. Some disruption can be tolerated at this level.

- Extreme hazard: Low-frequency/ high-consequence event. It is expected to occur far less often than the design hazard, but produce shocks on the built environment far exceeding their designed capability. There will typically be damage and some expected recovery period associated with such a hazard.

There is of course uncertainty surrounding the timing and likelihood of future hazards, as well as the level of damage a future hazard may cause. Uncertainty is discussed in a general sense in Section 6.

2.3.1.2 Discount rate

EDGeS requires the user to select a discount rate. Generally, communities and individuals consider one dollar to be worth more today than one year from now. The discount rate determines the extent to which a dollar in the future is worth in present day terms.

In EDGeS, the user is asked to input a real discount rate. The real discount rate is one that is adjusted for inflation.

This decision is crucial, as the discount rate affects affordability of a given resilience plan at a particular point in time. For most jurisdictions, the cost of obtaining capital is the most reasonable choice for discount rate. It also is important to keep in mind that different types of infrastructure projects may require different discount rates in any analysis.

2.3.1.3 Planning horizon

The timeframe over which resilience plans are assessed is important. A planning horizon—the period of years over which resilience plans are assessed and are compared in terms of costs and benefits that occur during that period—needs to be selected for the analysis (Gilbert et al. 2016).

For a given planning horizon, relevant costs and benefits must be fully and correctly considered. Some details are discussed in Section 4.3. The combination of the length of the planning horizon and the discount rate dictate the relative importance of future benefits and costs.

When defining costs and benefits in EDGeS, care must be taken if a proposed action that is part of a potential strategy ends before the planning horizon is reached. In that case, the projected net-benefit (costs and benefits) needs to be adjusted accordingly. For example, if a strategy includes an element that extends beyond the end of the planning horizon, then its residual value needs to be determined.

2.3.2 Costs

Costs associated with a given resilience strategy may occur once or multiple times over the life-cycle of a project under consideration. In measuring life-cycle costs associated with a given project alternative, all costs associated with owning, operating, maintaining, and disposing goods and services associated with the project directly or indirectly should be included.

2.3.2.1 Direct Costs

Direct (economic) losses are largely limited to losses of physical infrastructure. There are also direct costs associated with the set-up and maintenance of the resilience project, such as first costs and operation, maintenance, and repair (OMR) costs.

2.3.2.2 Indirect Costs

Indirect losses often result from other loss types and include impacts to the economy. Common indirect costs arise from inability to conduct business during and after a disaster event and the costs of unemployment due to disaster-related job losses.

Often indirect losses also fall into the category of non-economic damages typically includes loss of life and health impacts (primarily deaths and injuries), key governmental services, social networks and systems, and the environment. There is generally no market price for the things and services affected. The EDG (2016) provides a further discussion and examples of non-market costs and benefits associated with resilience planning in terms of estimating values.

2.3.3 Benefits

Benefits are divided loosely into two categories: 1. reductions in costs and losses during/from disasters and 2. non-disaster-related benefits. The first type of benefit is discussed in this section.

Benefits of resilience planning are seen as the improvement in performance during a hazard event over the status quo (i.e., business-as-usual) expected performance. Benefits may be obtained directly or indirectly by implementation of the new resilience strategy.

Fatalities averted during a disturbance is one type of benefit that is specifically delineated in EDGeS; there is a specific input screen dedicated to this class of averted costs. Not all plans will include this element (i.e., fatalities averted) and in some analyses the user may find it inappropriate to assign a statistical value to this element. Thus, it is optional input. This screen and input options in EDGeS is discussed further in Section 5.4.

Improvement in performance includes both reductions in the magnitude of damages (e.g., to property and livelihoods) from a disaster and in the costs of the response and recovery phases (Gilbert et al. 2016). Benefits (including avoided losses and costs), like costs, may be classified by their cause and to whom in the community it accrues, including: direct, indirect, response/recovery cost reductions, and non-economic. Of course, to be considered numerically in the economic output analysis non-economic benefits will need to have an estimated value assigned to them. Otherwise they may be noted in the tool in description sections of the screens.

It is important that the user ensures that costs and benefits are not double counted, especially when benefits arise from expected reductions in cost. One example is the consideration of savings on insurance premia counted as benefits (or equivalently deducted from the costs); in this case, benefits need to be considered as net of insurance pay-outs (pay-outs minus premiums paid) (Gilbert et al. 2016).

2.3.3.1 Direct Benefits

Direct benefits values are those that accrue to stakeholders without intervening factors or channeled through intermediaries. Examples include avoided damages when a disaster occurs.

2.3.3.2 Indirect Benefits

Indirect benefits are those values that accrue to stakeholders in a cascading manner. Examples arising from resilience planning include reduced business interruption and reduced unemployment payments due to disturbance-related job losses.

Indirect benefits might include reductions in business interruption losses due to non-hazard-related power or water outages.

2.3.3.3 Non-Disaster Related Benefits

Benefits also are considered to include positive effects (i.e., co-benefits) from a resilience strategy that improve community function and value on a day-to-day basis, in the absence of a disaster event. These non-disaster related benefits can be sub-categorized as: direct benefits, indirect benefits, and non-economic benefits. They should consider the benefits and costs that accrue during all phases associated with a hazard event, as well as under business-as-usual circumstances. The net co-benefits of resilience planning are sometimes referred to as the 'resilience dividend' (e.g., Rodin 2014). A discussion of the definition and theory behind co-benefits and co-costs is provided in Fung and Helgeson (2017).

Resilience investment options that achieve the same primary goal may differ with respect to co-benefits. For instance, levees and flood gates have related benefits to a community in the case of a flood event. Yet, conversion of a flood plain to green space used for recreation in the absence of flooding can also provide flood control in the case of a flood event; this option has greater co-benefits." An example of non-hazard-related indirect benefits is reductions in highway deaths and injuries from highway improvements.

To fully assess resilience alternatives, a community needs to consider co-benefits associated with each plan.

2.3.4 Externalities

Externalities are the inexplicit costs or benefits associated with a project. Externalities do not affect the resilience project or its stakeholders directly, but affect the net worth of the project to the wider community or others, such as members of a neighboring community.

Positive and negative externalities should be considered when considering the associated effects of a given resilience strategy.

For example, a positive externality may arise from improvements in a bridge's durability, which in turn cuts the amount of greenhouse gas emissions due to reduced maintenance needs. An example of negative externalities is that residents of homes near a transportation project that is part of a resilience plan may suffer from noise, dust, degraded air quality or traffic restrictions during and/or after construction.

In some cases, externalities and other impacts may or may not be quantifiable— they may have no defined market price. Identifying non-market considerations and valuing them when possible is discussed in Section 2.1. See the EDG (Gilbert et al. 2016) for further discussion.

2.4 Economic Evaluation Methods

There are numerous economic valuation methods and decision criteria that can be applied to a community resilience project. EDGeS provides the net present value of each alternative relative to the business-as-usual case.

Furthermore, the benefit-to-cost ratio (BCR), the internal rate of return (IRR), the return on investment (ROI), and ROI in the event of no disaster are provided for each alternative plan. These methods have been used for evaluating investments in buildings and building systems in the past, but are employed at the community level in EDGeS. They are discussed in greater detail in the following sections. Readers interested in mathematical derivations of the economic evaluation methods are referred to Appendix B of the EDG (Gilbert et al. 2016).

Since for most purposes these reporting approaches are equivalent, in each case the most appropriate approach should be selected based upon the audience within the community and those which are most easily interpreted by the CPT and the community's decision-makers.

2.4.1 Benefit-Cost Analysis

EDGeS provides benefit-cost analysis (BCA) through presentation of the *expected* net present value (NPV) of each defined alternative plan, using the user-defined discount rate over the provided time horizon. The NPV is the *expected* net present value due to the probabilistic approach in estimating the timing of future events. An *expected* value is the sum of all possible outcomes of an uncertain event multiplied by their corresponding probabilities. In the case of EDGeS, it is based on the average number of events to occur according to a Poisson distribution.

By comparing the NPV of each candidate resilience project, the user can determine the project that maximizes net benefits.

The BCA has two main purposes. First, it determines if a given candidate resilience plan is sound. In other words, it verifies whether the associated benefits outweigh the associated costs, and by how much, for that project alternative. Second, this approach provides a basis for comparing candidate projects; the total expected cost of each option is compared against its total expected benefits.

With respect to the base case, if the NPV is positive for a given alternative the investment is economical; if it is zero, the investment is as good as the base case; if it is negative, the investment is uneconomical.

In EDGeS the analysis of NPV for each alternative plan is given both including and excluding externalities. The inclusion of externalities is not an obvious decision in all cases and depends upon the community's decision makers' preference, the scope of the analysis, and how the boundaries of the community or government are defined.

It is important to note that in some cases constraints defined by the community that were deemed not possible to completely capture in monetary terms may be weighted heavily enough to deem an otherwise cost-effective option not appropriate. For example, highly politicized issues such as the use of eminent domain may create a disincentive to take a certain action.

The BCA value returned by EDGeS is given both including and excluding any externalities associated with a candidate strategy.

2.4.2 Benefit-to-Investment Ratio

The benefit-to-investment ratio (BCR) is a numeric ratio; its value indicates the economic performance of a given alternative plan instead of investing in the foregone opportunity. In general terms, the BCR is total benefits divided by the sum of investment costs and OMR costs.

The BCR for a given alternative is calculated by summing the net present value of all cash flows related to non-investment and non-OMR costs and benefits for the total planning horizon and dividing by the sum of the total investment costs and OMR costs related to the alternative. In this case cost reductions (savings), such as those from the on-hazard benefits, are treated as a benefit. It is important to note that, although these savings are treated as a benefit, they do not represent a positive cash flow in the sense that money is "gained" in the event of a hazard, instead they can be thought of avoided costs from implementing the resilience action.

When interpreting the BCR for a given alterative, a ratio less than 1.0 indicates that the given alternative is an uneconomic investment relative to the base case. Whereas a ratio of 1.0 indicates an investment with benefits or savings that just equal its costs. Finally, a ratio of greater than 1.0 indicates an economic project. In the context of EDGeS, any alternative that results in an BCR greater than 1.0 is designated as cost effective holding constant all other factors.

The BCR value returned by EDGeS is given both including and excluding any externalities associated with a candidate strategy.

Another calculation that is a variant of BCR is the savings-to-investment ratio (SIR) and is calculated as the savings divided by the total investment costs. The difference between SIR and BCR is that SIR assumes the primary benefit of the action is savings. If the resilience action were being looked at only in terms of hazard-related loss reductions, SIR would be more applicable, but by including the externalities and non-hazard related benefits, BCR becomes a more accurate measure. SIR can be easily calculated from EDGeS, as all values necessary for it are presented in the output.

2.4.3 Internal Rate of Return

The internal rate of return (IRR)[2] provides the average annual rate of return from an alternative project over the user defined time horizon. The IRR may be thought of as the discount rate at which the net present value of future cash flows is equal to the initial investment.

Generally, the IRR indicates the profitability and efficiency of an investment. This is in contrast with the net present value, which is an indicator of the net value or magnitude added by making an investment.

Applying the internal rate of return method to maximize the value of the firm, any investment would be accepted, if its profitability, as measured by the internal rate of return, is greater than a minimum acceptable rate of return. The appropriate minimum rate to maximize the value added to the firm is the cost of capital, i.e., the internal rate of return of a new capital project needs to be higher than the company's cost of capital. This is because only an investment with an internal rate of return which exceeds the cost of capital has a positive net present value.

However, the selection of investments may be subject to budget constraints, or they may be mutually exclusive competing projects, such as a choice between or the capacity or ability to manage more projects may be practically limited. In the example of a corporation comparing an investment in a new plant versus an extension of an existing plant, there may be reasons the company would not engage in both projects.

Furthermore, the IRR value returned by EDGeS is given both including and excluding any externalities associated with a candidate strategy.

[2] ASTM Standard E1057-06 (201) provides a discussion of IRR on the building and building system levels.

2.4.4 Annual Return on Investment

Annual Return on Investment (ROI) indicates the benefit to the community investing in the resilience project. In purely economic terms, it is one way of relating profits to capital invested. A relatively high ROI means the gains on the investment compares favorably to its costs. The ROI is used to evaluate: 1. the efficiency of an investment or 2. to compare the efficiencies of several different investments against each another.

Decision makers often compare the ROI to expected (or required) rates of return on money invested. It is also used as an indicator to compare different investments within a portfolio of potential alternatives. The investment with the largest ROI is usually prioritized; though the spread of ROI over the time-period of an investment should also be considered. ROI is not net present value-adjusted.

As discussed in Section 2.3.3.3., there are often non-disaster related benefits of a resilience-focused project. Due to the importance of considering these types of benefits, especially if a hazard may not take place within the time horizon considered, EDGeS provides a non-disaster ROI value. Furthermore, ROI and non-disaster ROI values both including and excluding any externalities associated with a candidate strategy is given in the EDGeS final analysis.

It should be noted, that ROI may be calculated in terms other than financial gain. For example, social return on investment (SROI) is a principles-based method for measuring extra-financial value (i.e., environmental and social value not currently reflected in conventional financial accounts) relative to resources invested. SROI tends to require detailed survey work within a given community, but is starting to be considered within community resilience planning processes. SROI can be used by any entity to evaluate impact on stakeholders, identify ways to improve performance, and enhance the performance of investments. Notes may be entered throughout EDGeS to help decision makers consider SROI aspects alongside ROI and other economic measures. See Nicholls et al. (2012) for more on the SROI.

2.5 Analysis Strategy—Overview

Developing a cost-effective community resilience plan is a complicated task. There is a great deal of uncertainty surrounding hazard events, from the occurrence rate to the associate magnitude of effect(s). There is also uncertainty surrounding the costs and benefits – some of these may be predictable (e.g., budget constraints or delays in funding), while others are not as predictable. This section explains baseline analysis based on point estimates, as well as sensitivity analysis, based on uncertainty around point estimates. Uncertainty is discussed in greater detail in Chapter 6.

2.5.1 Baseline Analysis

In analyzing alternative plans, the first level of analysis is referred to as the baseline analysis. In this type of analysis, the user inputs his/her best guess point-estimate values, which in turn are used to develop the estimated economic values discussed throughout this chapter for a candidate strategy. This is the approach demonstrated in Chapter 5 of this User's Guide.

The term 'baseline analysis' is used to denote a complete analysis in all respects but one—it does not address the effects of uncertainty. For some data, the user may feel that the input values are known with certainty. Other data are considered uncertain and the point values inputted for the baseline analysis may arise from a measure of central tendency (e.g., mean or median) or input from subject matter specialists.

2.5.2 Sensitivity Analysis

Sensitivity analysis measures the impact on projected economic indicators by varying the value of one or more data elements about which there is uncertainty. Sensitivity analysis can be performed for any measure of economic performance mentioned in Section 2.4 of this Guide. Generally, the sensitivity analysis complements the baseline analysis by evaluating changes in economic measures when selected fixed point data are allowed to vary around their baseline values in a manner defined by an uncertainty distribution defined by the user.

The user is not required to consider uncertainty in EDGeS, but it has the capability to deal with uncertainty surrounding: costs, benefits, externalities, and non-disaster related benefits.

The input of uncertainty distributions and boundaries around fixed point data estimates is discussed in Chapter 7.

The use of Monte Caro simulations in EDGeS is discussed further in Chapters 6 and 7.

3 Use of Case Studies

To help illustrate the use of EDGeS, as well as demonstrate some special situations and pitfalls that a user may experience in usage of the tool, resilience planning-related case studies have been created. These case studies construct fictional scenarios from an amalgamation of real-world examples and values from literature. Many simplifying assumptions are made in each to prevent the complexity of the examples from distracting from their illustrative purpose, while retaining enough complexity to be somewhat realistic.

Each example begins with a brief narrative to help set up the resilience scenario, followed by an explanation of the numbers used in the analysis, with numbers based on actual data being referenced to provide examples of places where numbers for use in EDGeS can be obtained (Any values lacking a reference are not based on literature and assumed for the purposes of creating this case study). In looking at potential sources that give figures from actual events, historical data from the same region is preferable. If this historical data is absent, then it may be necessary to look for similar scenarios elsewhere. It is important to make sure that any such sources used are credible and represent a scenario that is somewhat equivalent with that being analyzed (a new hospital in Los Angeles will not be comparable to a new hospital in a small town). While it is highly unlikely that there will be scenarios that match exactly, there may be some that share sufficient similarities to warrant use.

These case studies are meant to be illustrative and to exercise user's familiarity with EDGeS. The case studies are not analyses of actual policy option considerations. They are not intended to suggest that one form of mitigation strategy should be preferred over another and values at times have been selected to better help illustrate the use of EDGeS.

3.1 Case Studies—Overview

Four case studies have been developed:

1. An extended version of the *Riverbend* example from Appendix A of the *Economic Decision Guide* (2015), with added values based on the available input types in EDGeS. Riverbend, as described in this case study, is not a real location.
2. A case study examining the relocation of a hospital due to flooding concerns
3. A case study examining the choice between a buyout program or levee construction in reaction to flooding concerns
4. A case study examining wildfire mitigation in response to wildland-urban interface (WUI) fire concerns.

Each of these examples was developed for specific purposes, noted in Table 3.1. The *Riverbend* case study is developed in the following sections. All others may be found in Appendices B1-B3 of this User Guide.

Table 3.1 Purpose of case studies developed for the EDGeS User Guide

Case Study	Purpose
Riverbend	Basic example to illustrate the use of EDGeS
Hospital	Example to illustrate how more complex timing with costs can be analyzed in the current version of EDGeS
Buyout/Levee	Example used to illustrate potential pitfalls that may occur during analysis
WUI	Example to illustrate how to analyze differing return rates can be done in EDGeS

3.2 Riverbend Case Study

Riverbend, a small city of 50 000 people located in a valley along Central River, was originally settled 160 years ago by farmers and loggers. The city is comprised mainly of middle-class families with a median income close to the national average. Over that time period, the city has maintained much of its agricultural heritage while simultaneously cultivating robust manufacturing, finance, and real estate sectors in its economy. Recently, the logging and mining sectors have started to decline. Riverbend has managed to avoid major economic issues by attracting employers to other sectors.

The city maintains an important relationship with the neighboring city of Fallsborough, which is located on the other side of Central River. The two cities are linked by a four-lane interstate bridge that is vital to Riverbend logistically. The bridge represents the only route for traffic into the city. It routinely fails to meet the traffic demand during peak hours and is sensitive to earthquake events.

The Riverbend collaborative planning team (CPT) considered two alternatives to increase community resilience against seismic event hazards. Consideration of seismic events was driven by the known hazards in the region and the potential loss of life, infrastructure damage, and economic impacts if a disaster occurs. In developing their alternative resilience plans, the CPT assumed a 3 % real discount rate and a 50-year planning horizon. The design event was an earthquake with a 25-year return period. All discounting is performed using continuous compounding.

Plan 1. Upgrade the Central River Bridge (*Retrofit*)

The existing bridge is scheduled and budgeted for a deck replacement in 10 years, creating an opportunity to upgrade the bridge to be more resilient to seismic events. To upgrade the bridge, it must be closed to emergency services and regular traffic. The additional vehicle-hours from rerouting, as well as the effect on emergency vehicles, are real costs that must be considered. Heavier traffic on alternative routes will also decrease the life of those roads, as they may not be designed for the additional equivalent single axle loads they would be carrying.

Plan 2. Construct a Second Bridge Over the Central River (*New Bridge*)

The new bridge would be built with an offset alignment from the original bridge and according to current seismic codes and a design life of 125 years. The original bridge would continue to service traffic, but should a seismic event occur, all traffic will be maintained by the new bridge. Sharing traffic between the bridges will reduce traffic during peak hours that would benefit long-term economic development. Apart from the immediate benefits, the new bridge would be used to carry traffic when the old bridge eventually needs to be replaced and would also support a non-motorized path.

3.2.1 Assumptions

The following values are assumed for both alternatives:

Planning horizon: 50 years
Recurrence rate of Seismic Event: 25 years
Real discount rate: 3 %
Value of a statistical life: 7 500 000 USD

Other key assumptions have been made to simplify the example. These are not necessarily realistic and should not be considered prescriptive for an actual LCC analysis.

1. There is no dependence between distributions, for instance for distributions of cost and distributions of indirect cost. EDGeS currently does not implement such considerations, although for some distributions such dependencies would exist.
2. There is no uncertainty related to the return rate of the disaster.
3. Construction is assumed to occur entirely in year zero[3].
4. Construction externalities are negligible due to their assumed short time frame.
5. The analysis compares all values relative to the implicit option of doing nothing.

Assumptions related to specific values derived for the analysis are mentioned as they arise from the narrative.

3.2.2 Cost Data

Retrofit

Estimates place the direct cost (including engineering) of retrofitting the bridge at 3 000 000 USD[4], with an additional 500 000 USD in indirect costs (including costs of diverted traffic) based on Bhatt and Martinez (2013). Concerned about the realities of financing a project of this size, uncertainty estimates were also obtained. Based on typical values from literature, the planners estimate the upper end of the costs due to cost overrun to be 128 % the point estimates

[3] For an example that considers construction timing, see the *Hospital* case study in Appendix B.1.
[4] Based on estimate for bridge replacement for I-94 from Masonic Blvd. to M-29

(Flyvbjerg 2004). Although the planning team assumes the project being under-budget is highly unlikely, there is a chance a bid may come in under their estimate should they choose to retrofit and be on budget. The lower end is assumed to be 95 % of the point estimates. Triangular distributions were assigned accordingly. Additional operations, maintenance, and repair (OMR) costs are negligible.

New Bridge

The planning team divided the costs related to constructing a new bridge into two categories. The cost associated with constructing the bridge, and those associated with constructing new road and upgrading the existing road on either side of the river to accommodate the new bridge. The direct costs of constructing the new bridge are estimated at 4 250 000 USD [5]. This includes purchasing right-of-way, land acquisition, and environmental impact study, and engineering. Indirect costs are 175 000 USD based on values from Bhatt and Martines (2013), and include the indirect rate for the construction firm, as well as the costs of an environmental study. The new bridge would also add 25 000 USD a year in OMR costs. Triangular distributions are assumed for direct and indirect costs under the 95 % to 128 % range used for the retrofit costs. OMR uses a rectangular distribution bounded by 21 375 USD and 30 000 USD.

The additional road work is estimated to cost 2 500 000 USD in direct costs based on Florida Dept. of Transportation numbers[6], 150 000 USD[7] in indirect costs, and add a yearly OMR cost of 3710 USD (U.S. Forest Service 2011). Triangular distributions are assumed for direct and indirect costs under the 95 % to 128 % range used for the retrofit costs. OMR uses a rectangular distribution bounded by 3500 USD and 4250 USD.

3.2.3 Benefit Data

Retrofit

Event Related Benefits (*Benefits* screen in EDGeS)

A study[8] examining the benefits of retrofitting the bridge indicated that the retrofit would reduce direct losses by 260 000 USD, indirect losses by 2 000 000 USD, and response and recovery losses by 600 000 USD. A conservative estimate put the coefficient of variation (COV) for each category at roughly 0.3. Gaussian distributions[9] were assumed for all variables. These values represent reductions over the alternative of doing nothing assuming that the instigating disaster would produce identical losses every time.

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[5] Based on estimate for bridge replacement for I-94 from Masonic Blvd. to M-29
[6] Values estimated using Florida Dept. of Transportation's "Generic Cost Per Mile Models" <http://www.fdot.gov/programmanagement/Estimates/LRE/CostPerMileModels/CPMSummary.shtm>, retrieved in July 2017, and assuming 1.5 miles of new road
[7] Using a 6 % rate based on Florida Office of Inspector General (2013).
[8] The cost of completing this study is assumed already incurred, making it a sunk cost. Therefore, it is not included in the lifecycle cost analysis performed later.
[9] Also referred to as the normal distribution.

Fatalities Averted

By retrofitting the bridge, the possibility of a failure of a component, or the inability of an emergency vehicle to respond in a prompt time is reduced. This leads to fewer fatalities per disaster. Rough estimates put the number of fatalities averted at 0.1 per event.[10] The value of statistical life for both alternatives is 7 500 000 USD.

Non-Disaster Related Benefits (Resilience Dividend)

There are no assumed non-disaster related benefits to the retrofit. The bridge will continue to operate at original capacity after completion.

Externalities

No externalities are considered for the retrofit in this analysis. Realistically, there would be externalities; noise due to construction activity, or increased confidence in the bridge's safety, for instance.

New Bridge

Hazard-Related Benefits (*Benefits* screen in EDGeS)

A study on the earthquake-related loss reductions was commissioned for the new bridge alternative. There are no direct loss reductions, as the old bridge will behave identically to a scenario where no resilience action is taken and any damage it sustains will not affect the new bridge. For estimation purposes, it is assumed that the new bridge will perform as designed under seismic loading, and will therefore not increase the amount of direct losses. Indirect loss reductions are estimated to be 3 500 000 USD, due to no interruption to traffic flow across the river while the old bridge is repaired. Response and recovery losses are reduced by 1 000 000 USD due to the ability of emergency vehicles to travel easily across the river. As before these values are assumed to be normally distributed with a COV of 0.3.

Fatalities Averted

Unlike the retrofit alternative, the new bridge avoids fatalities by maintaining traffic flow, even if there is a failure on the old bridge. This allows emergency vehicles to continue to travel as

[10] Uncertainty around fatalities averted is being considered for a future iteration of EDGeS. Uncertainty output for fatalities averted in the current version of the tool is related to uncertainty in the recurrence rate.

needed across the river. In total, 0.2 fatalities[11] are expected to be averted under the new bridge alternative.

Non-Disaster Related Benefits (Resilience Dividend)

The new bridge helps reduce travel time during peak flow by providing alternative lanes and better roads on either side of the bridge. A study found this would save 100 000 USD per year in vehicle-hours lost in traffic[12]. A triangular distribution is assumed for these savings, with a low value of 70 000 USD and a high value of 115 000 USD.

Externalities

Transportation projects are traditionally associated with negative externalities. New roads bring traffic, which brings noise and pollution to the local area. That is not the case here. It is assumed that traffic stays constant after construction, so no new noise would be associated with the new bridge and by reducing vehicle-hours in traffic, the amount of pollution decreases. Using data from Queensland Australia's government (Department of Transport and Main Roads 2011), and assuming the new bridge saves the following in travel distance:

- The equivalent of 1 car 1000 km in travel distance a year,
- The equivalent of 1 light freight vehicle carrying 6.8 tonnes 200 km in travel distance a year[13]
- The equivalent of 1 heavy freight vehicle carrying 22.8 tonnes 75 km in travel distance a year,

the annual reduction in externalities due to water pollution can be estimated to be 39 081 USD, and externalities due to greenhouse gasses are 77 329 USD. Additionally, the walking path increases community connectivity, producing another 39 799 USD in positive externalities. This highlights an important step that must be taken if using outside data sources. All relevant values must be converted to a consistent dollar unit, i.e., 2017 U.S. Dollars, to account for inflation and other price changes (specific changes in local labor market and prices as represented by the consumer price index)[14].

[11] Indicating injuries and no deaths.
[12] This analysis assumes that traffic volume remains constant and no economic growth occurs in both alternatives. In practice, a more efficient road network would attract more users and more regional or local growth. As before, the cost of the study is assumed as a sunk cost.
[13] The definition of light and heavy freight comes from U.S. Dept. of Transportation (2014). Capacity uses the mid-range from Table 3-8 of U.S. Dept. of Transportation (2014) converted to metric tons.
[14] This was not necessarily done for every value in all case studies. Some values, like the value of a statistical life, are set by governmental agencies and only change when updated, while others were used "as is" to enhance results interpretation. In practice all values that are inflation dependent must be brought to a consistent U.S. dollar year.

Under uncertainty analysis, these externalities are assumed to follow a discrete distribution with three values; low, with a 0.25 probability, most likely (Mode), with a 0.5 probability, and high, with a 0.25 probability. Specifically:

- Greenhouse gases: Low - 64 043 USD, Mode - 77 329 USD, High - 81 387 USD
- Water pollution: Low - 24 587 USD, Mode - 39 081 USD, High - $56 566 USD
- Linking communities: Low - 21 750 USD, Mode - 39 799 USD, High - 53 006 USD

3.2.4 EDGeS inputs

This section summarizes the inputs into EDGeS for each of the two resilience plans being considered by Riverbend, described in detail previously. These values will be of use in reviewing the features of EDGeS as well as in the Tutorial on the use of the EDGeS (See Appendix A).

Analysis Parameters (applicable to both alternatives):

- Planning horizon: 50 years
- Recurrence rate of Seismic Event: 25 years
- Real discount rate: 3 %
- Value of a statistical life: 7 500 000 USD

Point Estimate Analysis

Table 3.2 summarizes the input into EDGeS for the *Retrofit* alternative[15], ignoring uncertainty. The input for the *New Bridge* alternative is provided in Table 3.3[16]. All cost values are assumed to occur at year zero.

Table 3.2 EDGeS input for Retrofit option using point estimates

Class	Item	Retrofit
Costs	Direct Costs	$3 000 000
	Indirect Costs	$500 000
On-Disaster Benefits	Direct Loss Reduction	$260 000
	Indirect Loss Reduction	$2 000 000
	Repair and Replacement Loss Reduction	$600 000
Estimated Fatalities Averted[17]		0.1

All costs are assumed at starting at year zero, with all OMR costs being yearly. The resilience dividend is assumed to begin accruing annually in year one, as do all externalities. All externalities are assumed to be owned by the community.

[15] For brevity, any potential EDGeS inputs for which there were no values in the alternative are omitted from this and all future tables.
[16] For brevity, all tables in this document with mixed units use *$* before a dollar amount to denote USD
[17] Although this benefit occurs on earthquake occurrence, it is separated from the input for other on-disaster benefits in EDGeS to account for differences in input.

Table 3.3 EDGeS input for New Bridge option using point estimates

Class	Item	New Bridge
Costs	Bridge Construction Direct Costs	$4 250 000
	Bridge Construction Indirect Costs	$175 000
	Bridge Construction OMR Costs	$25 000 annually
	Additional Roadwork Direct Costs	$2 500 000
	Additional Roadwork Indirect Costs	$150 000
	Additional Roadwork OMR Costs	$3710 annually
On-Disaster Benefits	Indirect Loss Reduction	$3 500 000
	Repair and Replacement Loss Reduction	$1 000 000
Estimated Fatalities Averted		0.2
Resilience Dividend	Reduced Commute Time	$100 000 annually
Externalities	Reduced Greenhouse Gas Emissions	$77 329 annually
	Reduced Water Pollution	$39 081 annually
	Better Linking of Communities	$39 799 annually

Analysis under uncertainty

Table 3.4 summarizes the input into EDGeS for the *Retrofit* alternative under uncertainty. The input for the *New Bridge* alternative is provided in Table 3.5. All cost values are assumed to occur at year zero.

Table 3.4 EDGeS input for Retrofit option under uncertainty

Class	Item	Distribution Type	Parameters
Costs	Direct Costs	Triangular	Low – $2 850 000 Most Likely – $3 000 000 High – $3 840 000
	Indirect Costs	Triangular	Low – $475 000 Most Likely – $500 000 High – $712 500
On-Disaster Benefits	Direct Loss Reduction	Gaussian	Mean – $260 000 Std. Dev – $78 000
	Indirect Loss Reduction	Gaussian	Mean – $2 000 000 Std. Dev – $600 000
	Repair and Replacement Loss Reduction	Gaussian	Mean – $600 000 Std. Dev – $180 000
Estimated Fatalities Averted		Deterministic	Value – 0.1

All costs are assumed to start in year zero. Additionally, all OMR costs reoccur annually. The resilience dividend is assumed to begin accruing value annually in year one, as do all externalities in this example. All externalities are assumed to be owned by the community planning the resilience project.

Table 3.5 EDGeS input for New Bridge option under uncertainty

Class	Item	Retrofit	
Costs	Bridge Construction Direct Costs	Triangular	Low – $4 037 500 Most Likely – $4 250 000 High – $5 440 000
	Bridge Construction Indirect Costs	Triangular	Low – $166 250 Most Likely – $175 000 High – $224 000
	Bridge Construction OMR Costs[b]	Triangular	Low – $21 375 High – $30 000
	Additional Roadwork Direct Costs	Triangular	Low – $2 375 000 Most Likely – $2 500 000 High – $3 000 000
	Additional Roadwork Indirect Costs	Rectangular	Low – $142 500 Most Likely – $150 000 High – $180 000
	Additional Roadwork OMR Costs[b]	Rectangular	Low – $3500 High – $4250
On-Disaster Benefits	Indirect Loss Reduction	Gaussian	Mean – $3 500 000 Std. Dev – $1 050 000
	Repair and Replacement Loss Reduction	Gaussian	Mean – $1 000 000 Std. Dev – $300 000
Estimated Fatalities Averted		Deterministic	Value – 0.2
Resilience Dividend	Reduced Commute Time[b]	Triangular	Low – $70 000 Most Likely – $100 000 High – $115 000
Externalities	Reduced Greenhouse Gas Emissions[b]	Discrete[a]	Low – $64 043 Most Likely – $77 329 High – $81 387
	Reduced Water Pollution[b]	Discrete[a]	Low – $24 587 Most Likely – $39 081 High – $56 566
	Better Linking of Communities[b]	Discrete[a]	Low – $21 750 Most Likely – $39 799 High – $53 006

[a] Low has a 0.25 probability of occurrence, Most Likely has a 0.5 probability of occurrence, High has a 0.25 probability of occurrence
[b] Annually Recurring

4 Basic Features of EDGeS: Getting Started

In what follows, all screen shots were taken from the Riverbend case study discussed in Section 3.2. Appendix A contains a detailed tutorial on using EDGeS.

Version 1.0 of EDGeS is sent to users in a zipped folder via NIST Secure File Transfer, upon request. The user will then have to download the file and extract the folder by right clicking on the zipped folder and selecting *Extract All*. Once extracted, the *EDGeS* folder may be saved in any convenient location. Characteristics of a good location are that it can be easily found and will not be accidentally deleted. With these qualifications, the Downloads folder is likely a poor choice. Good options include the Documents folder and the Local Disk. In the main folder, there is an executable named 'EDGeS.exe.' To start the program, the user must double-click on this executable.

A short-cut to this executable can be created by right-clicking on the file and selecting *Make Shortcut*. The new file, 'EDGeS – Shortcut.exe,' can be saved anywhere on the computer. For example, the user may choose to save the *EDGeS* folder on the Local Disk (typically this is the C drive) and create a shortcut that is saved on the Desktop. By double-clicking on the Desktop shortcut, the program will open, and it is unlikely that the folder will be accidentally moved or deleted from that location.

When the user opens EDGeS, two screens will load. The first screen (i.e., the black screen) is the console. The console displays errors and warnings if they occur. The console can be ignored (minimized), but must remain open. (Closing it will additionally close the second screen and abort the program.) The second screen is the opening page of EDGeS, as shown in Figure 4.1. From this page, the user may either: 1. start a new analysis or 2. open an existing analysis by selecting the appropriate radio button and clicking *OK*.

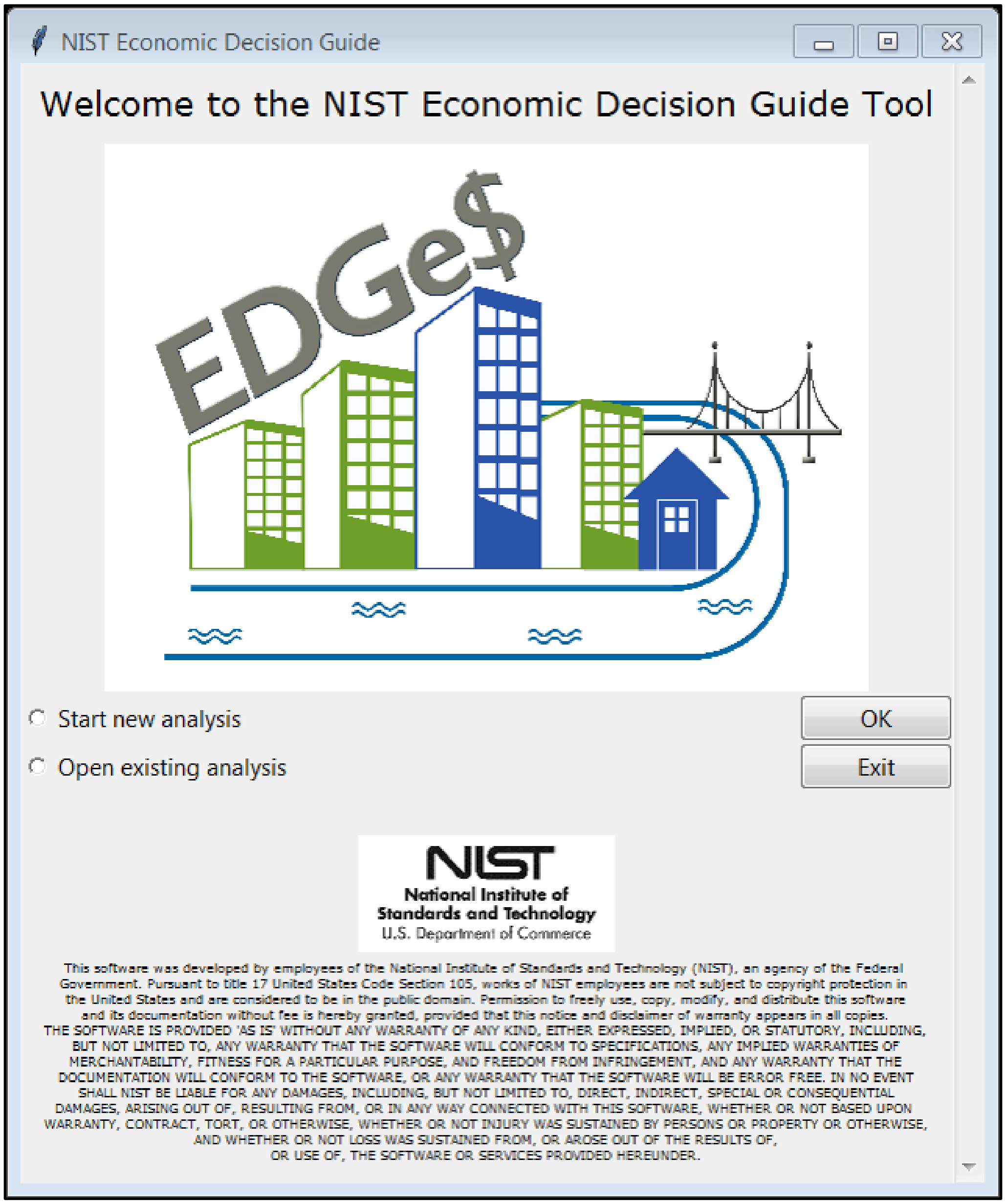


Figure 4.1 *Opening* page of EDGeS

Selecting *Exit* or clicking the 'x' button at the top right corner of the EDGeS opening page will cause the program to quit.

4.1 Opening a Project File

Selecting the 'Open existing analysis' option will cause the program to open a file dialog page prompting the user to select the file for the existing analysis. This .csv[18] file will be built by EDGeS after completing an analysis. While it is recommended to use the EDGeS GUI to construct the save file, the user may create a save file from scratch using Appendix C. After

[18] All file extension formatting follows the Apple Style Guide (Apple 2013).

opening the file, the program will bring up the *Menu* page, which can be read about in Section 5.1.

Reading-in the file will take some time, dependent on the size and complexity of the project. The user is advised not to do anything until the *Menu* page is showing—which indicates that the file has loaded and is ready to be edited.

If the file selected does not have the proper extension, an error pop-up message will appear, stating: "The file selected was not a .csv file and thus could not be a save file. Please select a different file." If the selected .csv file is not a properly formatted save file, an error pop-up message will appear, saying, "The save file chosen is an improperly formatted save file. Please choose a different file." To avoid this error, users are recommended to keep a separate folder for input files. The *Opening* page will remain open until a properly formatted save file is chosen.

Once a project file has been selected, the only way to open a different project file is by closing the program and relaunching EDGeS.

4.2 Creating a Project File

Selecting 'Start new analysis' on the *Opening* page will bring the user to the *Project Information* page described in Section 5.2. After completing the *Project Information* page, the user will be prompted to choose a save name for the file. The user is highly encouraged to save their analysis regularly using the *Save Analysis* button available on most pages.[19]

After starting a new analysis, a different project file can only be accessed by closing the program and opening it up again.

[19] This button is not available on the *Menu* page (described in Section 5.1), the *Project Information* page (described in Section 5.2), or either of the in-tool pages for viewing the analysis (described in Section 8.1). To save from the *Menu* page, the user may navigate to any other page. Any time the user navigates away from the *Project Information* page, the program will save. If the user has any in-tool pages for viewing the analysis, the *Analysis Information* page (described in 8.1) will also be present, from which the user may save their project.

5 Entering Data without Uncertainty

Though uncertainty can be added to a project before all parameters (e.g., costs and benefits) have been defined, for the sake of simplicity this section will deal only with entering data in point value form. Adding uncertainty around these point values with EDGeS will be discussed in Section 7.

Clicking *Next* to work through the program sequentially the user will see the pages in the order indicated in Table 5.1.

Table 5.1 Order of the pages in EDGeS (if following the natural progression of EDGeS)

Page order (following the *Project Information* Page)	**Page Title / Description**
1.	*Costs*
2.	*Costs Uncertainties*
3.	*Externalities*
4.	*Externalities Uncertainties*
5.	*Benefits*
6.	*Benefits Uncertainties*
7.	*Fatalities Averted*
8.	*Non-Disaster Related Benefits*
9.	*Non-Disaster Related Benefits Uncertainties*

The user is encouraged, but not required, to follow the workflow of the EDG (2016).

Please note that the pages associated with *Uncertainties* (2, 4, 6, and 9 in Table 5.1) will be presented and discussed in detail in Section 7.

5.1 *Menu* Page

The first page displayed when opening a previously-defined analysis is the *Menu* page, as shown in Figure 5.1. Every page has a button that will allow the user to return to the *Menu* page. From this page, the user can access any of the pages described in the rest of this section, any of the *Uncertainties* pages as described in Section 7, or run the analysis as described in Section 8.1.

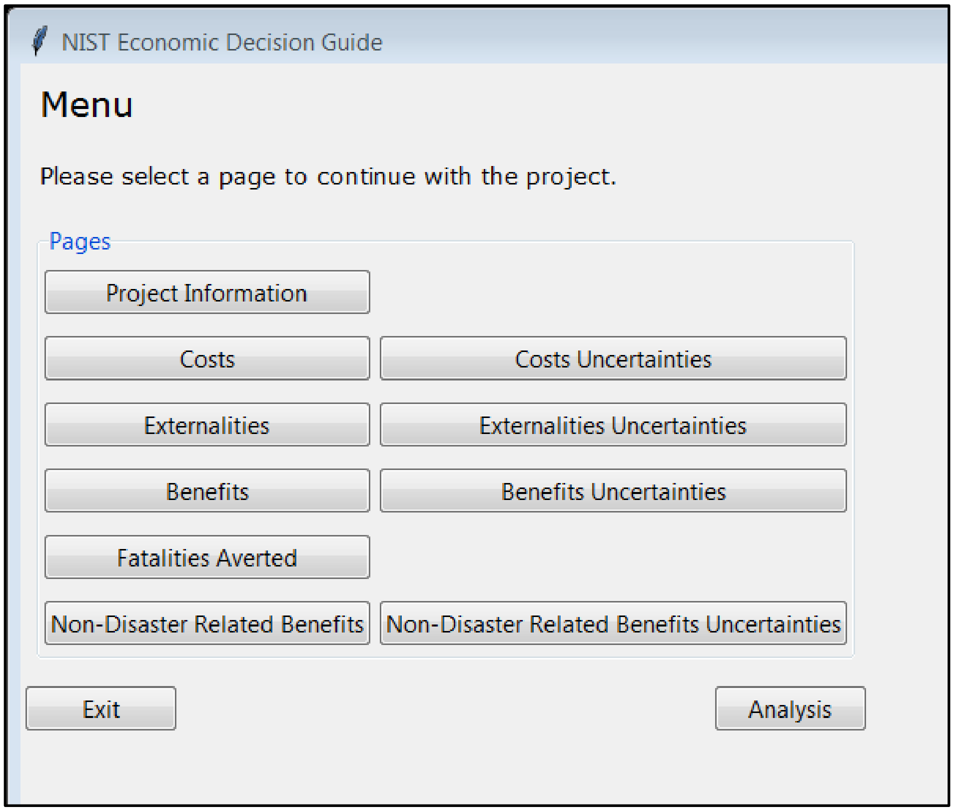


Figure 5.1 The *Menu* Page

Clicking *Exit* on this page or on any other page in the program will cause the program to quit. Data that has been entered, but not yet saved, will be lost.

5.2 Project Information Page

Any information shared across plans is input on the *Project Information* page, as seen in Figure 5.2. The text at the top of the page provides a brief description about the purpose of the page and contains a *More Information* button. When clicked, the *More Information* button produces a textbox with more information about the various fields and their associated requirements.

Every field on this page except for *Risk Preference* and *Hazard Magnitude* must be filled out by the user, as it contains critical information about the project and the ability to perform the subsequent analysis. The project name will be used as a header on any file exports (see Figure 8.2) and may not contain a comma. The planning horizon and real discount rate are used for all final analysis calculations; these values must be defined as a number greater than zero (i.e., $x > 0$). Hazard recurrence is also used for all final analysis calculations and must be a number that is zero or greater (i.e., $x \geq 0$).

The number of alternative plans and their associated titles are necessary to inform the program how many plans to make available in future pages and which names to use in referring to them. It is recommended that the user picks names that will avoid confusion when assigning costs, benefits, and externalities further on in EDGeS. The *Hazard Magnitude* and *Risk Preference* are not required fields, as they are not currently used in the calculations. If included, hazard magnitude must be a number that is zero or greater.

Both *Hazard Recurrence* and *Hazard Magnitude* allow the user to define uncertainty around the point estimates entered on this page. A detailed discussion of that functionality is presented in Section 7.2.

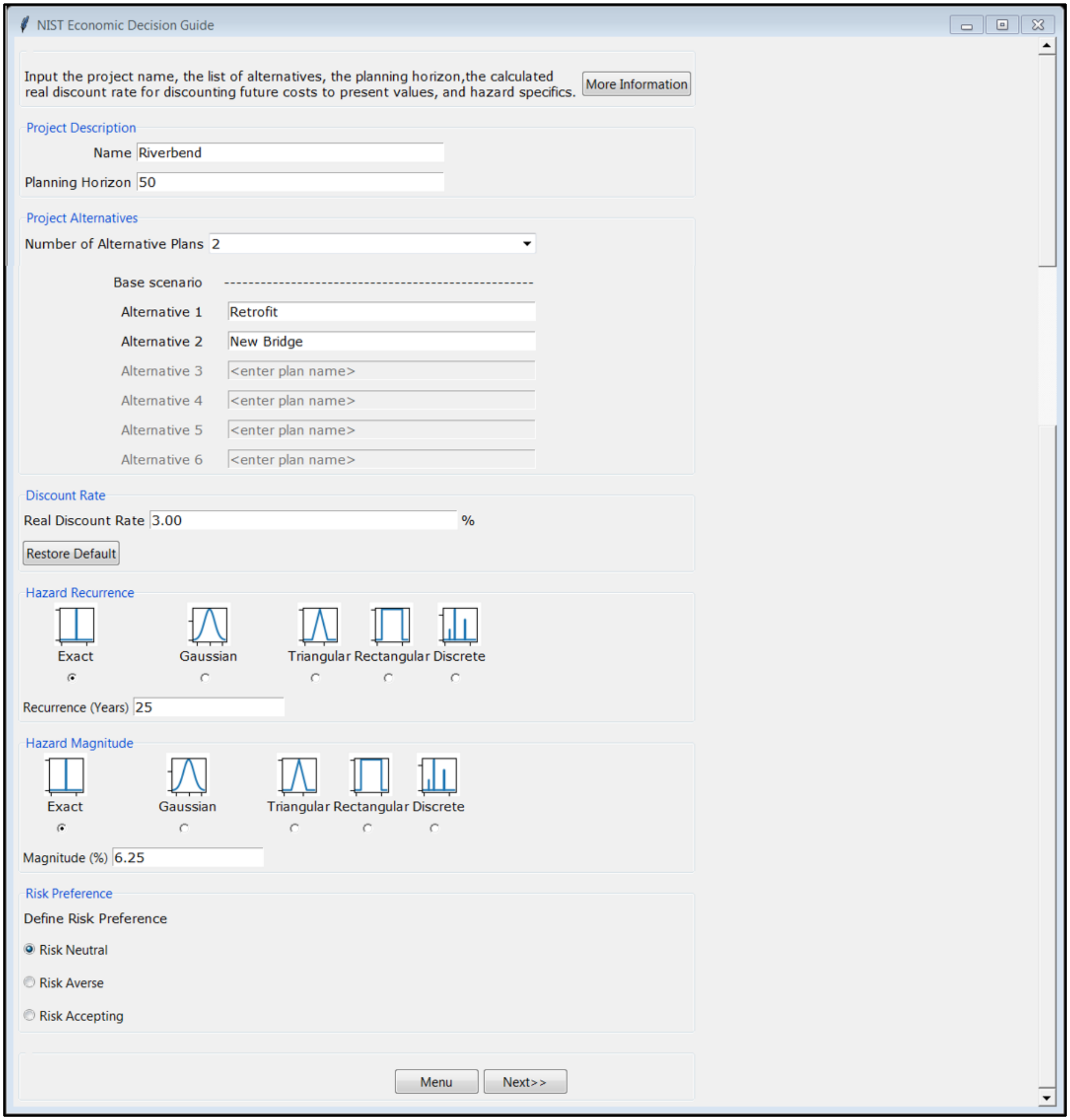


Figure 5.2 The *Project Information* page

Upon completing the *Project Information* page, the user may click *Next* or *Menu* and will be prompted to save the file. This save will happen any time the user navigates away from this page. The user may choose to: 1. create a new save file or 2. to save over an existing file. EDGeS save files are .csv files. Upon saving the file, *Next* will take the user to the *Costs* page (5.3.1) where they may begin progression through the pages and *Menu* will take the user to the *Menu* page (5.1).

5.3 Page Layout

The pages that allow the user to input costs, externalities, benefits, and non-disaster related benefits were designed to share many similar features in order to ease usability of EDGeS. This section describes the features that these pages all have in common. All images (Figure 5.3-Figure 5.13) used to describe these common features are taken from the *Costs* page as a demonstration. In what follows, an entire cost, externality, benefit, or non-disaster related benefit will be referred to as an 'item.' For the components discussed, each page will appear nearly identical except for the page title and some minor details. An example of what the entire item page looks like can be seen in Figure 5.3; this graphic puts in context all the page sub-sections that will be discussed throughout this section.

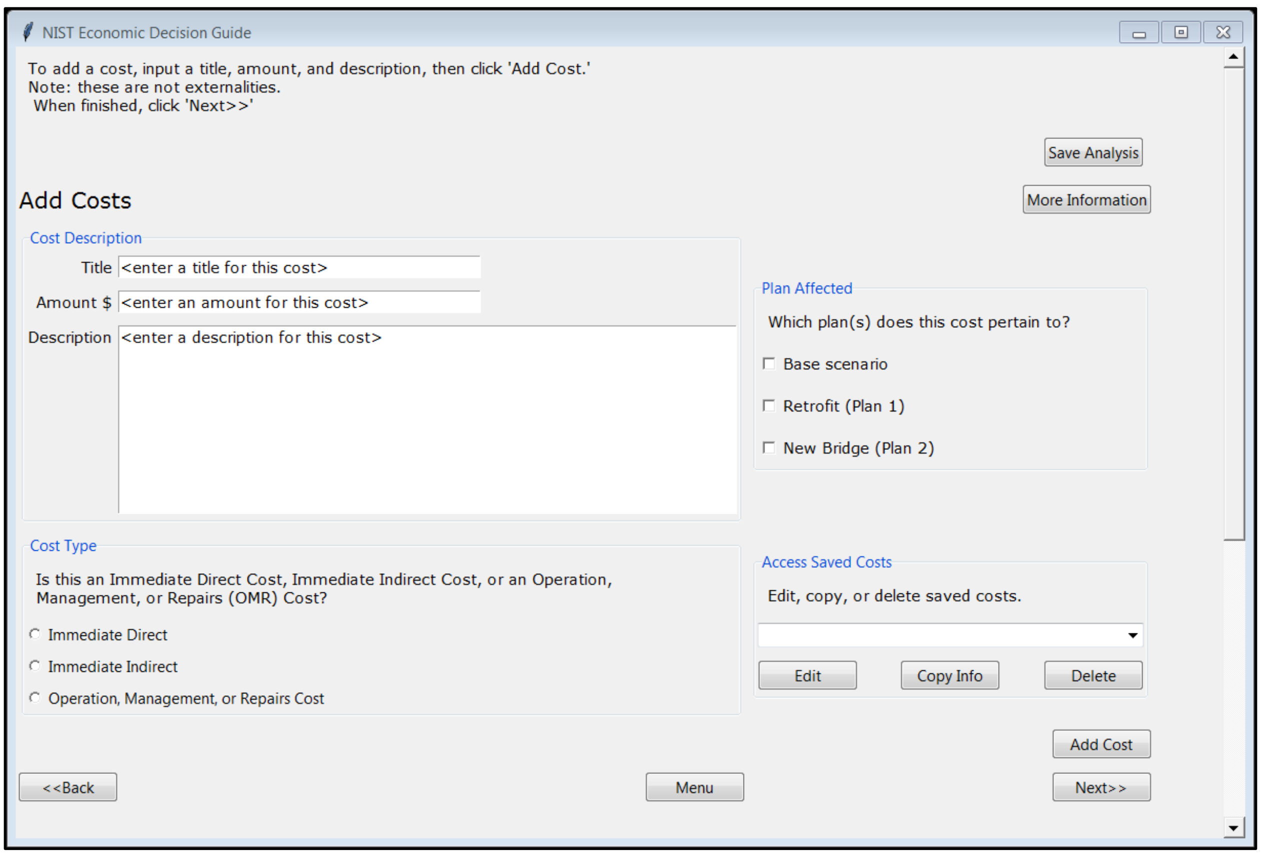


Figure 5.3 The Costs page as an example

Every page has a header, as seen in Figure 5.4, that gives a brief description of the contents of the page, a title for what aspect is being entered on that page, an option to save the analysis with all changes, and a *More Information* button. The header pictured in Figure 3.3 is specific to the *Costs* page; however, the layout is the same on each page.

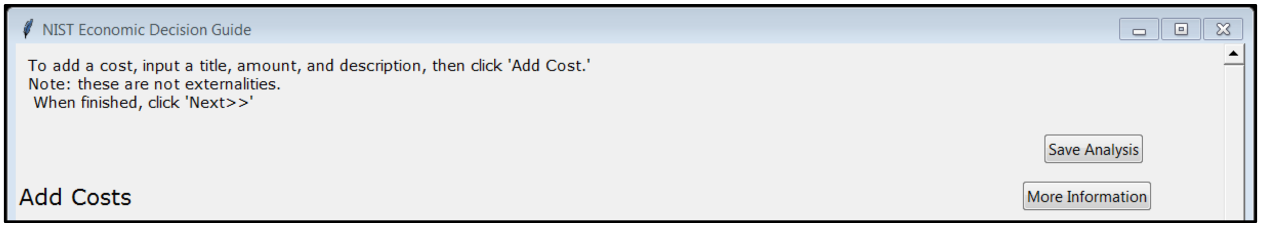


Figure 5.4. An example of the page header from the *Costs* page

The title informs the user of how any items entered on that page will be treated in the final analysis. In the example of costs, all items constructed on this page are treated as costs in the analysis. Any time the user selects *Save Analysis*, the program will prompt the user to choose a filename for the analysis. The user may save over the file that is currently read in or may choose a new file name. It is highly encouraged to save progress regularly. The *More Information* button will bring up a pop-up that will give guidance on individual fields and usage of the page.

Below the header, every page features a *Description* component, as seen in Figure 5.5. This component is where the user will enter the title, amount, and description of the item they are saving. Both the title and the amount are mandatory fields. The title must not contain a comma, and each plan may have only one item with a given title. The numeric amount must be zero or greater. Filling in the *Description* field is optional.

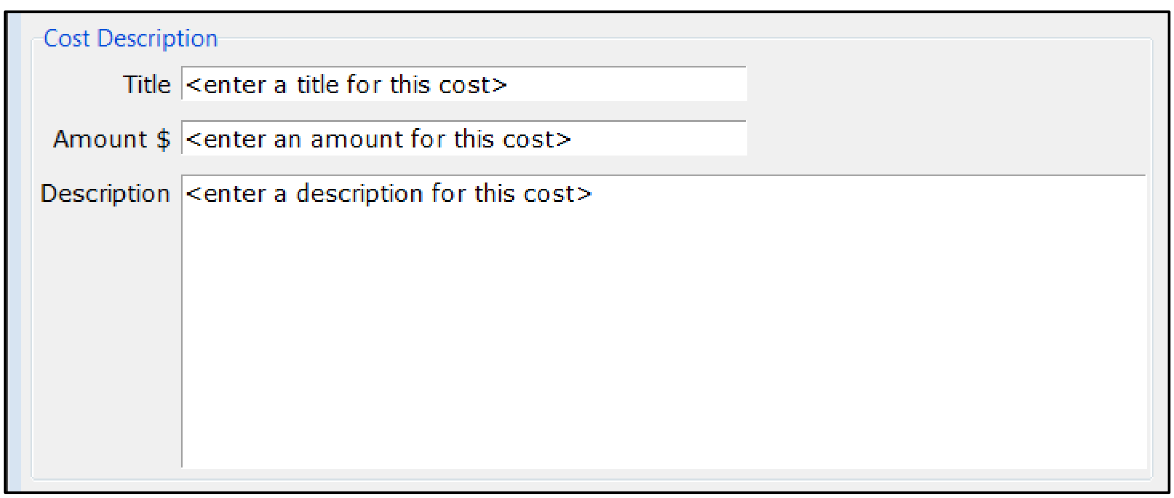


Figure 5.5 An example of the *Description* component from the *Costs* page

The title will be used to distinguish items from one another, not only on this page, but also in the Word export file, as described in Section 8.2.2, and when dealing with uncertainty, as described in Section 5.3. Inputs from the *Description* field will be visible in the Word export file.

To the right of the *Description* component is the *Plan Affected* component, seen in Figure 5.6. For the final analysis, each item must be associated with at least one plan, which is signaled by checking the appropriate box(es). The component will list out all available plans with their titles as set by the user on the *Project Information* page.

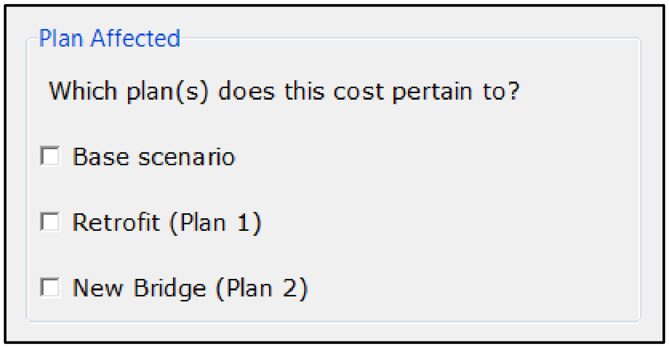


Figure 5.6 An example of the *Plan Affected* component with three plans, the base scenario, the Retrofit plan, and the New Bridge plan

If a single item is applied to two (or more) plans, the item is saved as two (or more) unique instances—one applied to each of the selected plans. Thus, any future edits in one plan will not be applied to the same item in another plan.

Beneath the *Plan Affected* component is the *Access Saved Items* component, as seen in Figure 5.7. This component is labeled with *Access Saved* and whatever item type the page represents, here *Costs*. It allows the user to edit, copy, or delete saved items of that type.

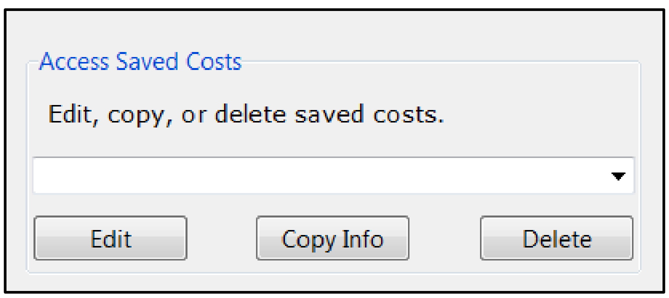


Figure 5.7 An example of the *Access Saved Items* component from the *Costs* page

The user may use the dropdown menu, as seen in Figure 5.8, to view all items of the page type that have been saved by name and the plan with which each item is associated.

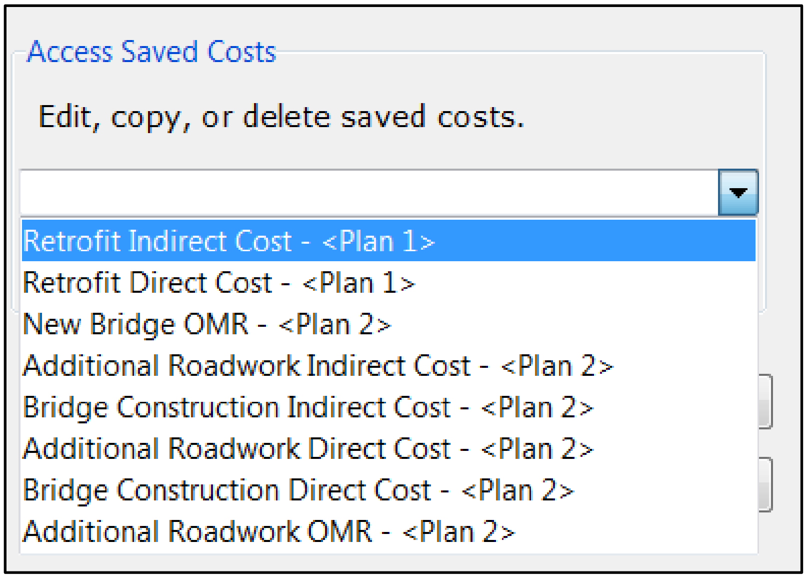


Figure 5.8 An example of the *Access Saved Items* dropdown menu from the *Costs* page, using the costs from the Riverbend example

After selecting an item, the user may choose to '*Edit*, *Copy Info*, or *Delete*.'

Edit will fill the page with all the information about the selected item and then the user is given the choice to *Cancel Edit*, which will return the item to its previous state or to *Edit* which will save the edits, as seen in Figure 5.9. Editing an item will clear any associated uncertainty to avoid inadvertently setting uncertainties, which may be no longer valid or sensible for the edited item.

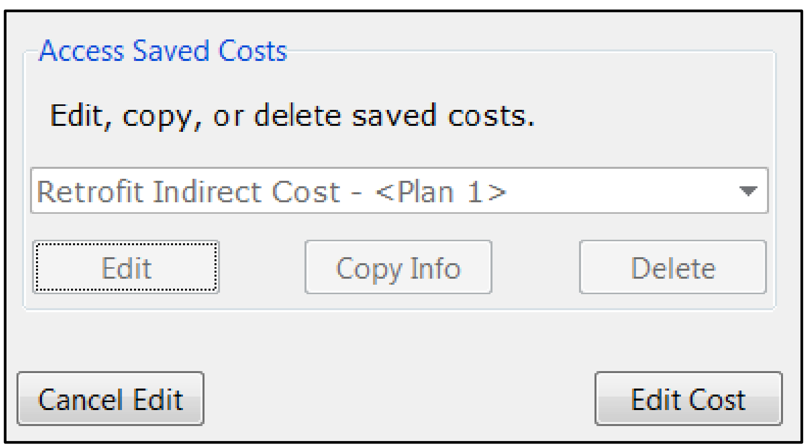


Figure 5.9 An example of editing an item using the Retrofit Indirect Cost from the Riverbend example

Copy Info fills the page with all the information about the selected item except for the *Plan Affected* component. The user must choose which plan is affected and may make any necessary changes in this new item before saving. If the item being copied has an uncertainty associated with it, the uncertainty is not copied. *Delete* will bring up a pop-up message, seen in Figure 5.10, the prompts the user to confirm their intent to delete the item with its title, amount, and description.

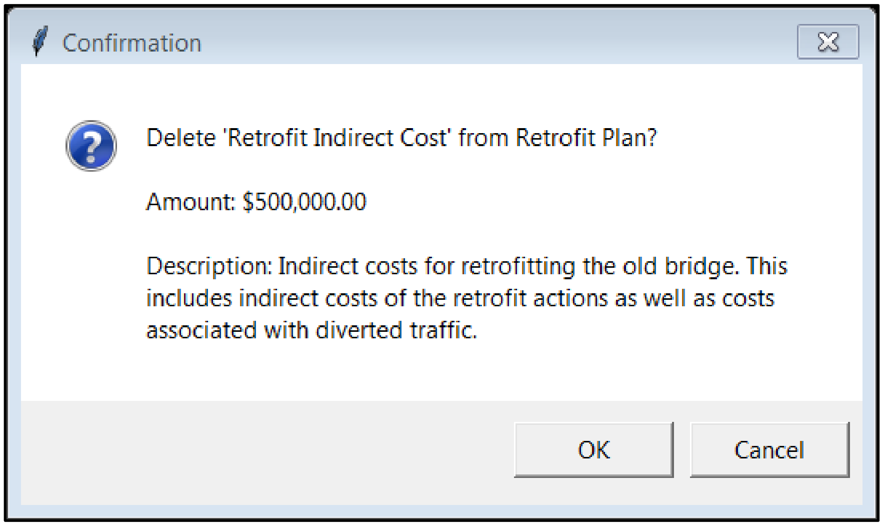


Figure 5.10 Confirmation of *Delete* action

The bottom of the page contains the *Navigation* component, as displayed in Figure 5.11. The navigation component allows the user to: 1. return to the previous page using the *Back* button, 2. continue to the next page using the *Next* button, 3. move to the *Menu* page using the *Menu* button, or 4. save an item while remaining on the page using the *Add* button.

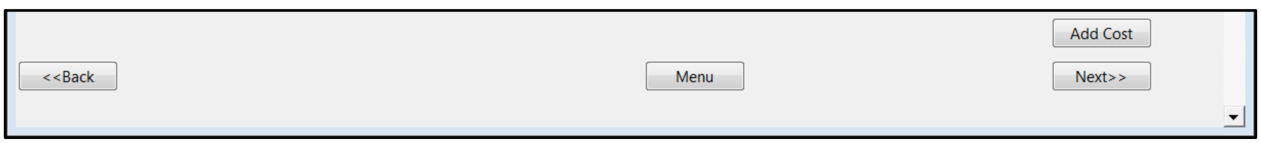


Figure 5.11 The *Navigation* component

Unless the page is blank, navigation buttons will validate and save the page content. If the *Back*, *Next*, and *Menu* buttons encounter a failed validation, the user will be informed of why the validation failed and asked to choose whether to change pages without saving or to finish editing the item, as can be seen in Figure 5.12.

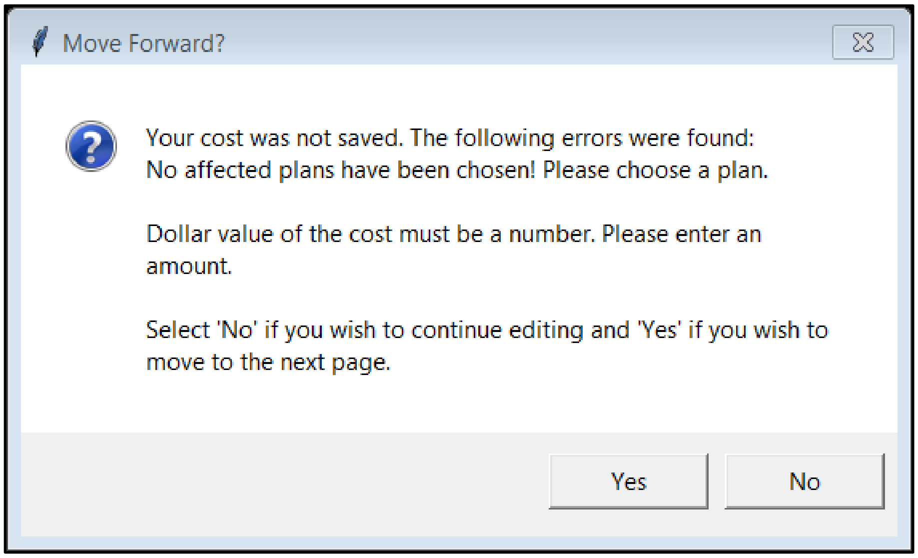


Figure 5.12 Confirmation to leave page

If the *Add* button encounters a failed validation, the user will be informed why the validation failed, as can be seen in Figure 5.13. In the provided example, the user left the *Plan Affected* component and the *Amount* field from the *Description* component blank.

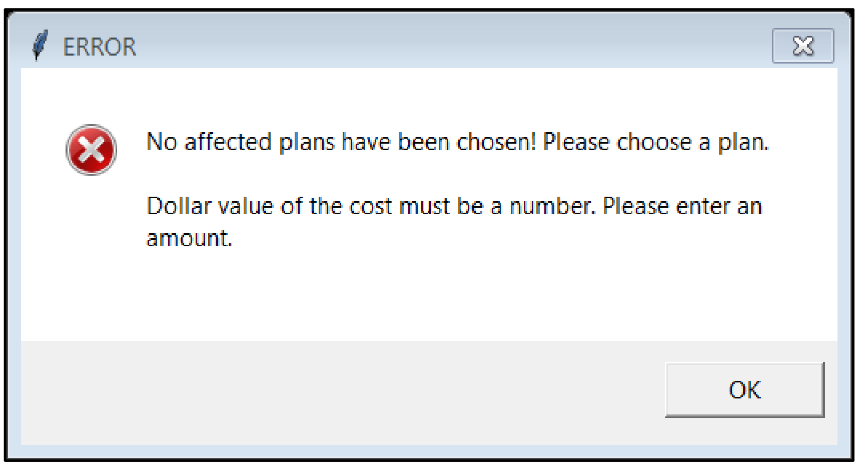


Figure 5.13 Failed validation notification

In addition to these components, each page has components that make it unique and are described below in Sections 5.3.1 through 5.3.4.

5.3.1 Costs Page

Any costs associated with plans are entered on the *Costs* page, seen in Figure 5.14.

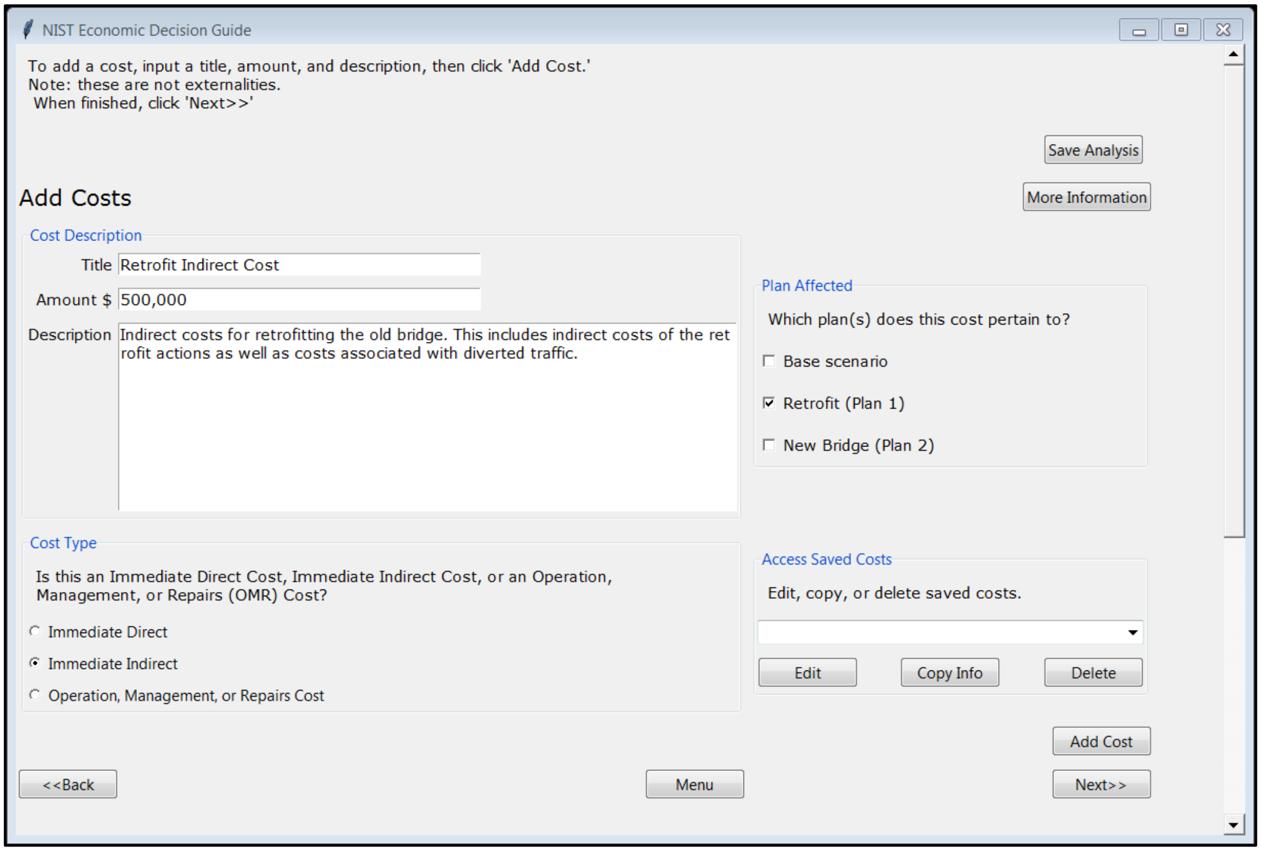


Figure 5.14 The *Costs* page

In addition to the standard components, the *Costs* page requires that the user defines the type of cost. The *Cost Type* component prompts the user to select whether the cost is an ‘Immediate Direct’ cost, an ‘Immediate Indirect’ cost, or an ‘Operation, Management, or Repairs’ (OMR) cost, as can be seen in Figure 5.15.

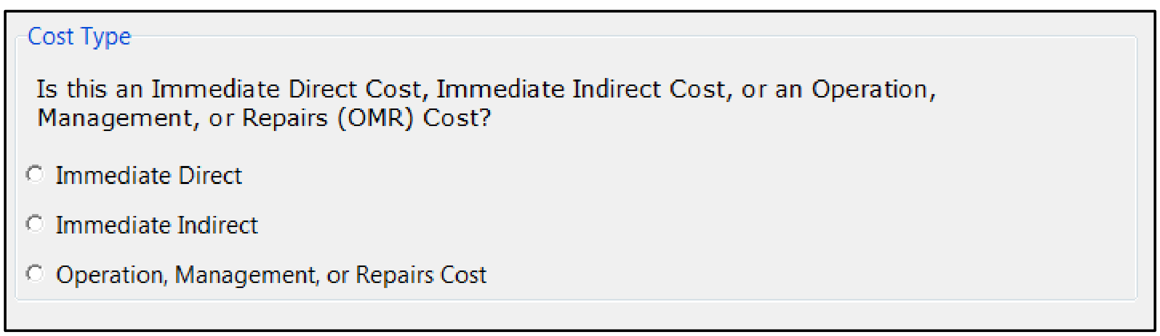


Figure 5.15 The *Cost Type* component

If the user selects OMR, another field will appear, prompting the user to define *OMR Details*. These details include selecting if this is a 'One-Time Occurrence' or a 'Recurring' cost, as can be seen in Figure 5.16.

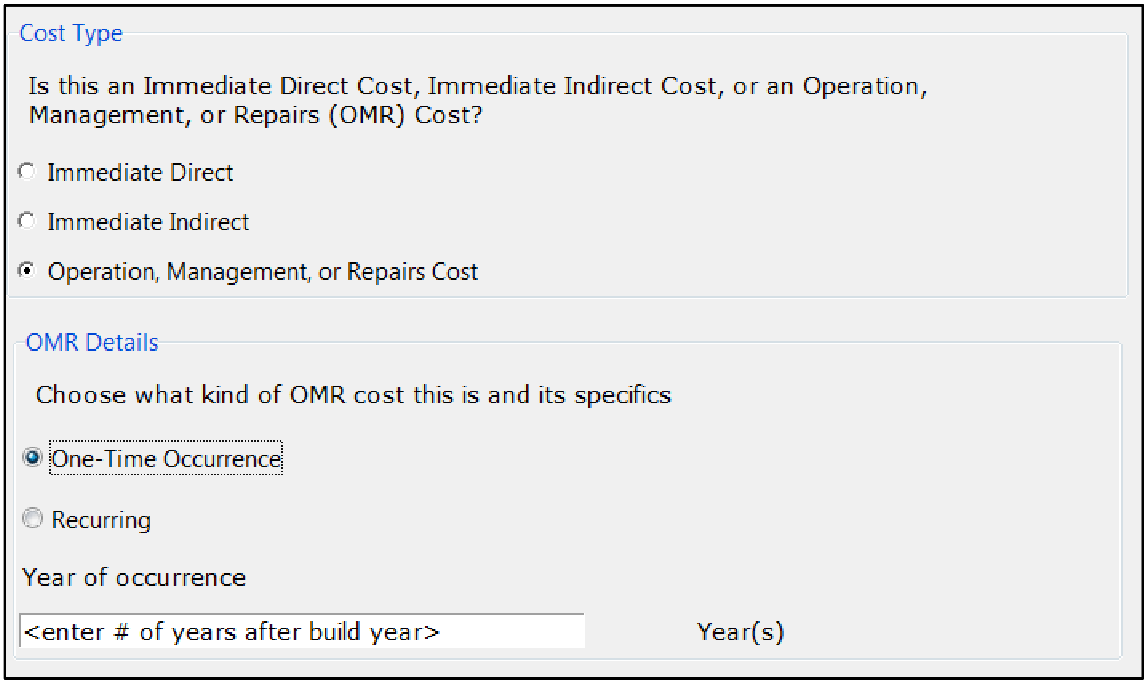


Figure 5.16 The *Cost Type* component with OMR selected as *One-Time Occurrence*

If 'One-Time Occurrence' is selected, the user will need to input the year at which to apply the cost relative to the first year of the analysis, which is defined as year zero. If 'Recurring' is selected, the user will additionally need to input the rate at which the cost occurs, as can be seen in Figure 5.17. The *Year of occurrence* must be defined as zero or greater. The *Rate of occurrence* must be greater than zero.

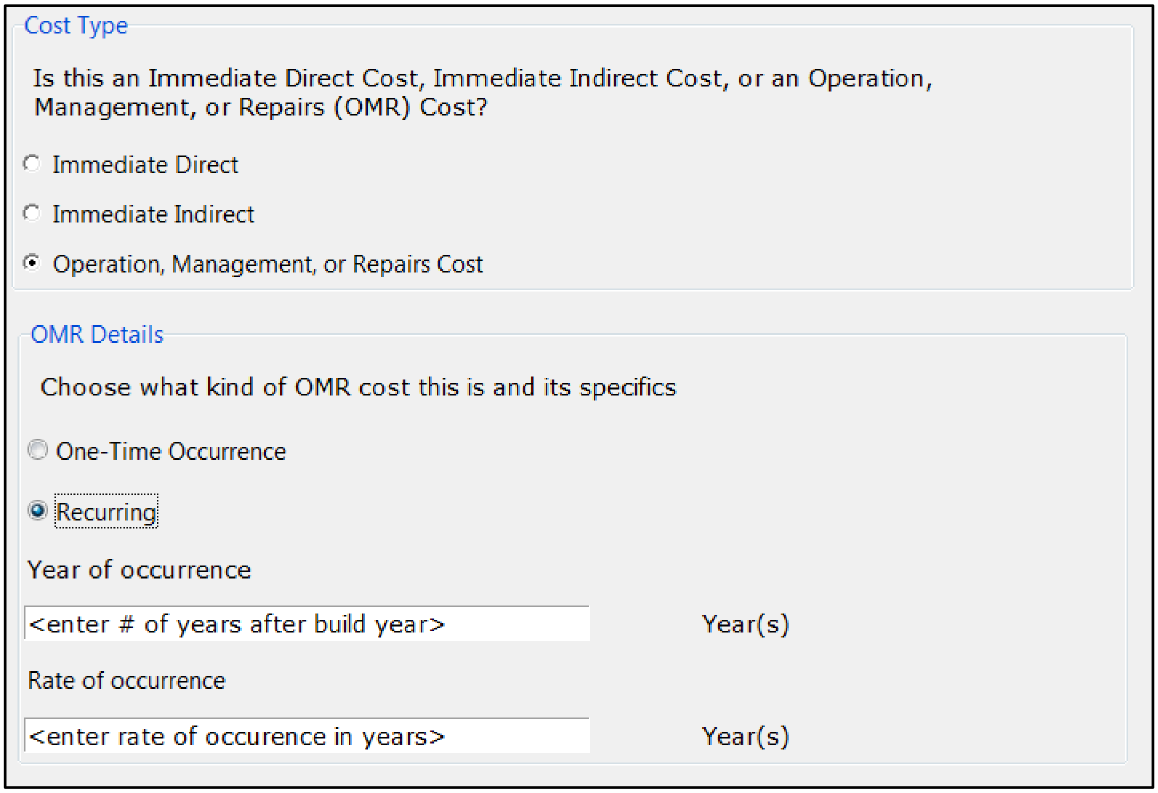


Figure 5.17 The *Cost Type* component with OMR selected as *Recurring*

To start a recurring cost immediately (i.e., in the first year of the analysis), the user must set the *Year of occurrence* to zero.

Any completed cost can have uncertainties added on the *Cost Uncertainties* page. Adding uncertainties in EDGeS is described in Section 7.

5.3.2 Externalities Page

Externalities are entered on the *Externalities* page, seen in Figure 5.18.

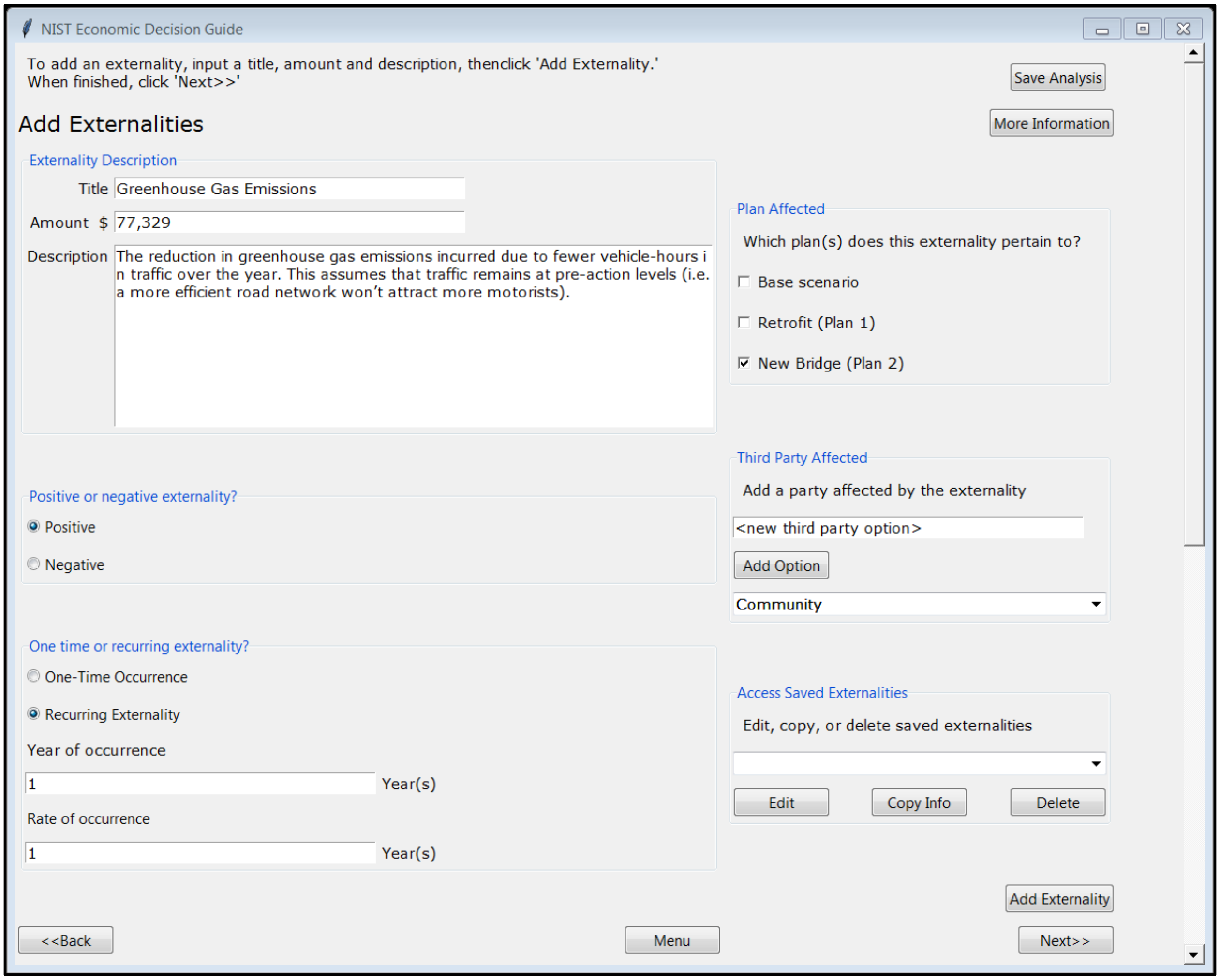


Figure 5.18 The *Externalities* page

In addition to the standard components, the *Externalities* page requires information on: 1. whether an externality is positive or negative, 2. if the externality is a one-time occurrence or if it is recurring and what years to apply said externality, and 3. which third-party is affected by the externality.

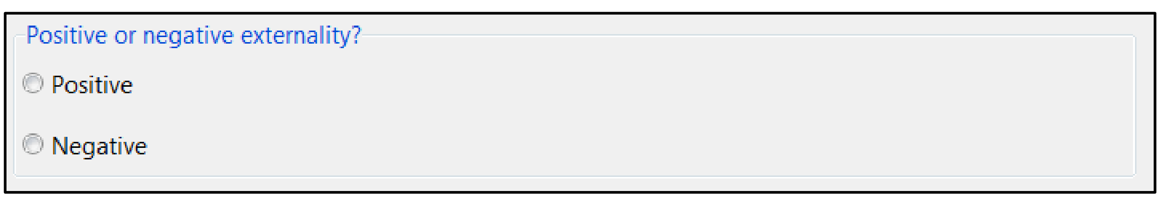


Figure 5.19 The *Positive or negative* component

The *Positive or negative* component, seen in Figure 5.19, consists of two radio buttons. This information is required for the final analysis.

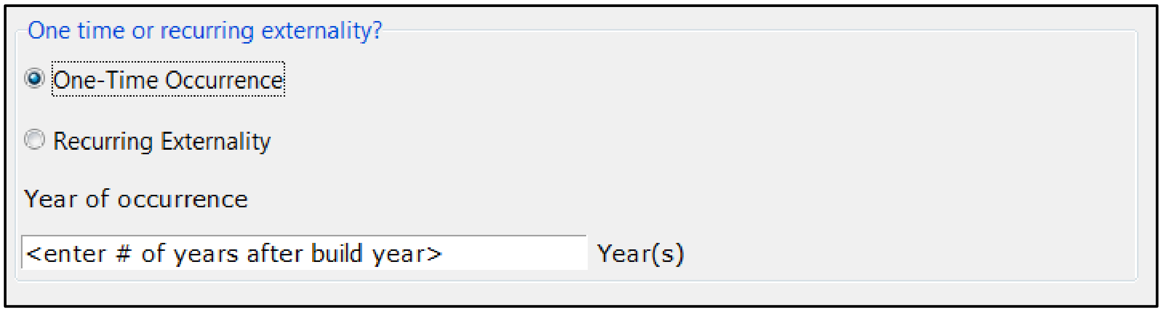


Figure 5.20 The *Recurrence* component with One-Time Occurrence selected

The *Recurrence* component allows the user to select if the externality recurs or if it is a one-time occurrence. If the user selects 'One-Time Occurrence,' as is shown in Figure 5.20, the program requires an entry as to in which year the externality should be applied; this value must be zero or greater. To apply the externality along with any immediate costs, the user must set the *Year of occurrence* to zero. If the user selects 'Recurring Externality,' the *Rate of occurrence* field will appear, as seen in the full Externalities page, Figure 5.18. The rate of occurrence must be a number greater than zero.

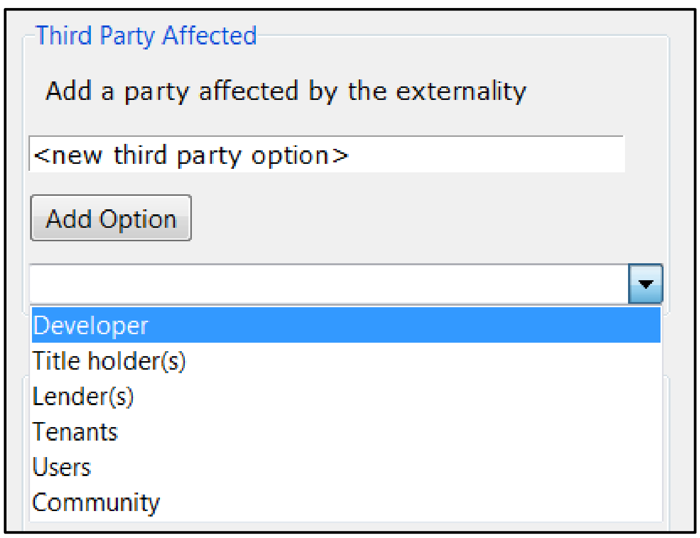


Figure 5.21 The *Third Party Affected* component

The *Third Party Affected* component, seen in Figure 5.21 allows users to assign a third party affected by the externality from a dropdown menu. The program begins with the menu populated with the following options:

- Developer
- Title holder(s)
- Lender(s)
- Tenants
- Users
- Community

If the user wishes to assign a third party that is not already in the list, the field above the dropdown menu allows the user to type in their option and click *Add Option*. The new option will be added to the dropdown menu for selection. If used as the 'third party affected' for an externality, this additional third party option will be available whenever this file is read in to the program. If not used, this additional third party will remain in the dropdown menu only until the program is closed.

Any completed externality can have uncertainties added using the *Externalities Uncertainties* page. Adding uncertainties is described in Section 7.

5.3.3 Benefits Page

Benefits are entered using the *Benefits* page, seen in Figure 5.22.

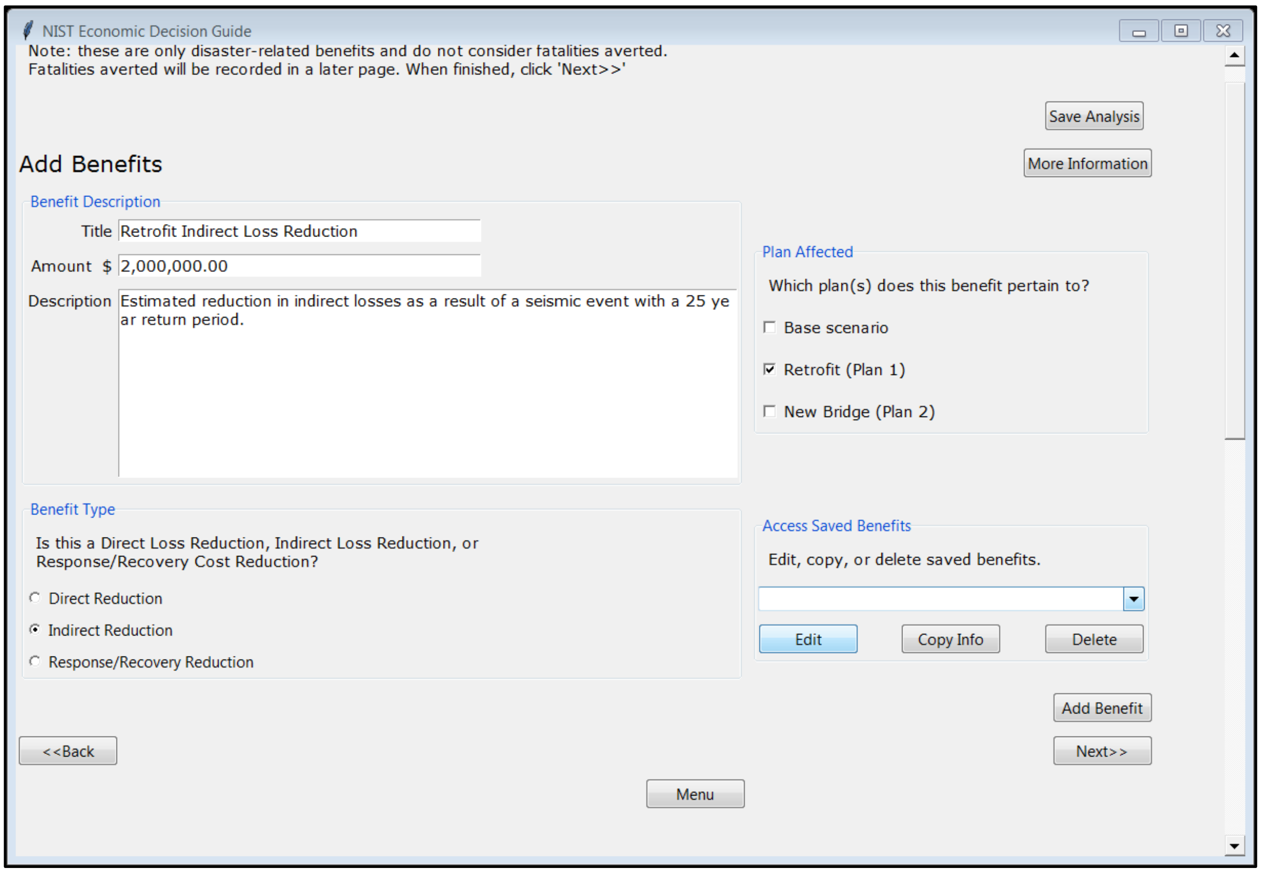


Figure 5.22 The *Benefits* page

In addition to the standard components, the *Benefits* page prompts the user to identify the benefit type, in the component seen in Figure 5.23. The user is given three options: 1. a direct loss reduction, 2. an indirect loss reduction, or 3. a response/recovery cost reduction.

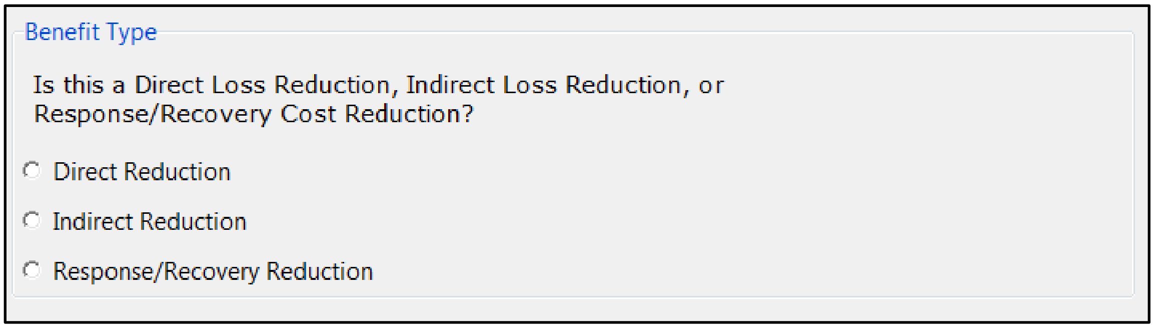


Figure 5.23 The *Benefit Type* component

Benefits entered on this page are treated as reductions of loss in the event that the disturbance (as outlined on the *Project Information* page) occurs.

Once a benefit has been entered, uncertainty may be added as is described in Section 7.

5.3.4 Non-Disaster Related Benefits Page

Non-disaster related benefits are entered on the *Non-Disaster Related Benefits* page, seen in Figure 5.24.

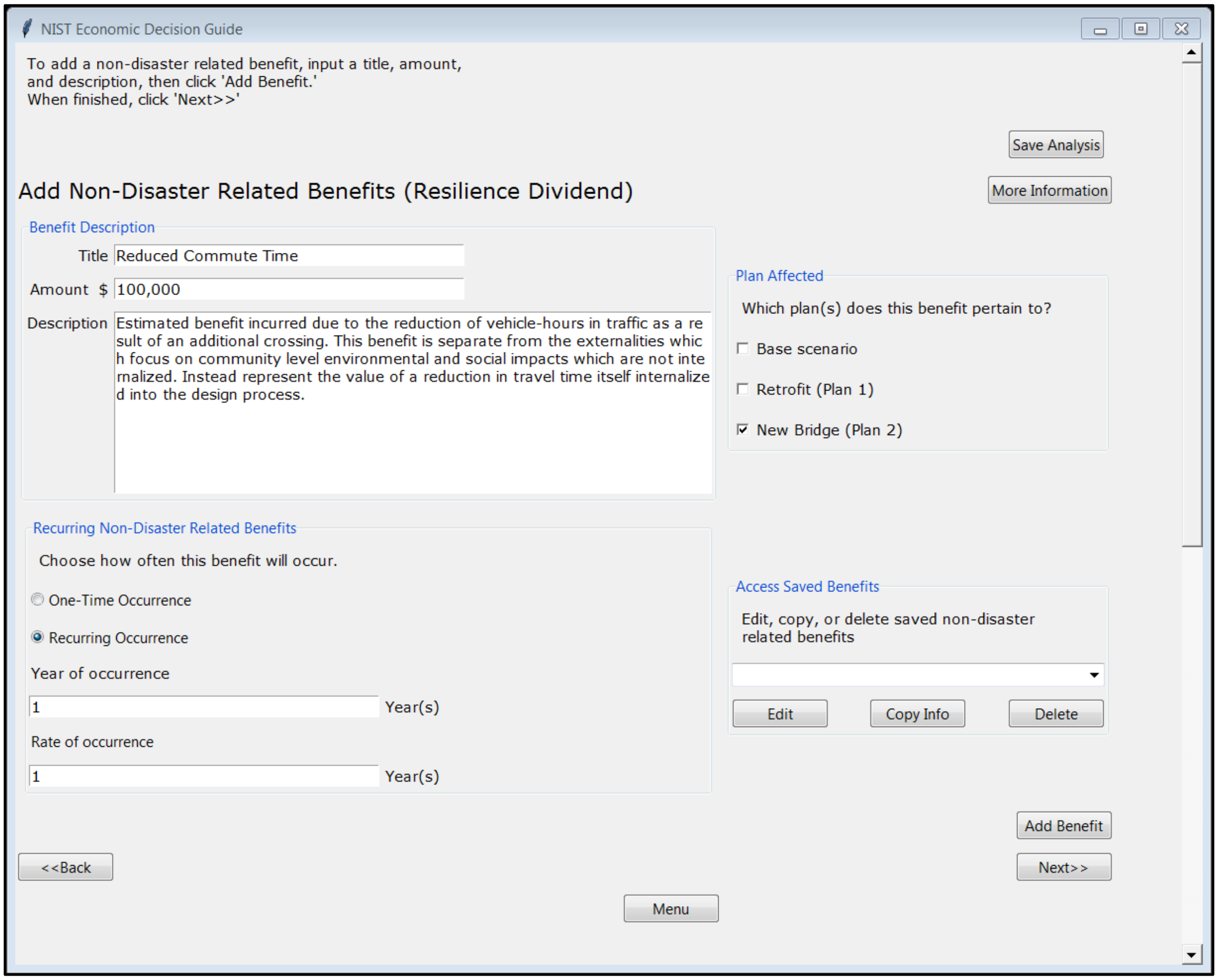


Figure 5.24 The *Non-Disaster Related Benefits* page

In addition to the standard components, the *Non-Disaster Related Benefits* page has a *Recurrence* component.

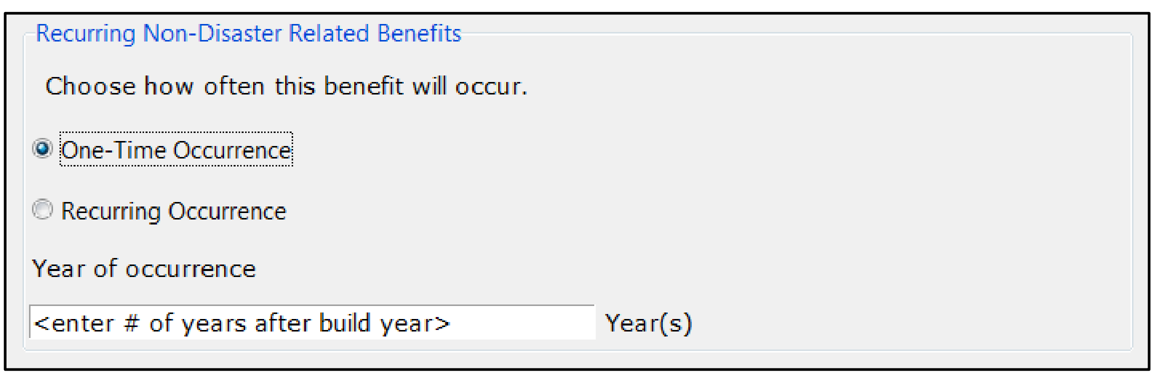


Figure 5.25 The *Recurrence* component

The *Recurrence* component allows the user to select if the benefit is recurring or if it is a one-time occurrence. If the user selects one-time, as is shown in Figure 5.25, the program requires an entry as to what year the benefit should be applied, which must be a number that is zero or greater. To apply the benefit along with any immediate costs, the user must set the *Year of occurrence* to zero. If the user selects recurring, the *Rate of occurrence* field will appear, as seen in Figure 5.20. The *Rate of occurrence* must be a number greater than zero.

Any completed non-disaster related benefit can have uncertainties added using the *Non-Disaster Related Benefits Uncertainties* page. Adding uncertainties is described in Section 7.

5.4 Fatalities Averted Page

The *Fatalities Averted* page, as seen in Figure 5.26, does not have the same components as the previous pages. Each plan can only have one entry for fatalities averted, whereas a given plan can have multiple associated costs and benefits. The standard components present are the page header, as seen in Figure 5.4 and the navigation component, as seen in Figure 5.11.

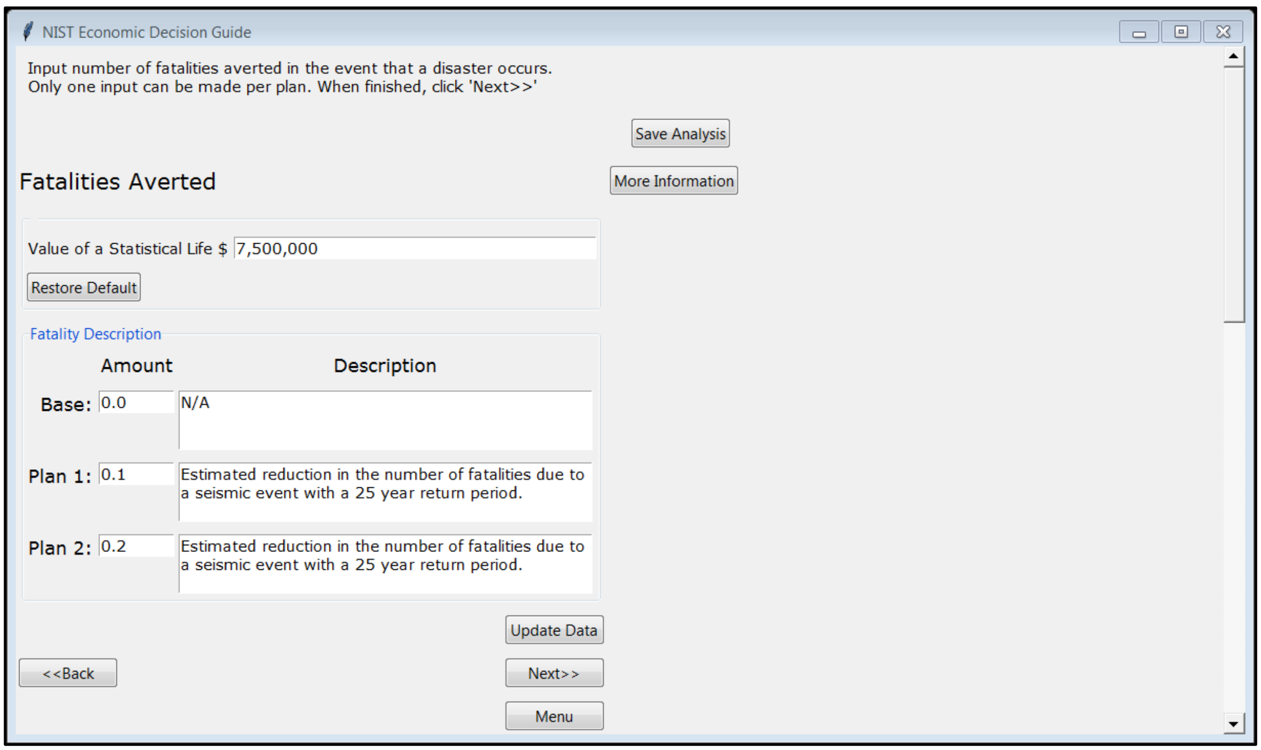


Figure 5.26 The *Fatalities Averted* page

The top field is the *Value of a Statistical Life*, which has a default value of 7 500 000 USD but can be set to any number zero or greater by the user. Clicking *Restore Default* will set this field to the default value. The main component lists out the plans by number and allows for a numerical input and a description. Clicking *Update Data* will save the data without changing the page. Because the number of fatalities averted is necessary to perform calculations, each plan is given a default of zero fatalities averted, and the user may increase that value.

6 Treatment of Uncertainty

As noted in Section 2.5, there are uncertainties in factors that affect the present net values (PNV) estimated across alternative resilience plans. These uncertainties include, but are not limited to: the timing and likelihood of future hazards, the amount of damage a future hazard will cause, future costs of mitigation strategies, and uncertainty about the validity of models used to estimate present expected net benefits (Gilbert et al. 2016).

Additionally, while economic analysis should consider all possible consequences of a hazard event, the CRPG recommends consideration across at least three hazard levels –routine, design, and extreme (NIST 2016), as noted in Section 2.3.1.1. These three outcome levels may be considered through uncertainty in the resulting costs averted in the case of a hazard event.

Since it is important to consider estimated expected costs and benefits associated with competing investment scenarios, assumptions about benefits in the event of a hazard occurrence (e.g., the expected reduction in losses) should consider the uncertainties of outcomes. Of course, typical uncertainties related to estimating costs also must be factored into the EDGeS analysis when the user can provide such information. Some of those uncertainties will depend on the timing and severity of the disaster itself, like response and recovery costs. But others will arise from typical uncertainties, such as those related to budgeting.

EDGeS offers specific guidance about performing uncertainty analyses based upon user-defined probabilities around point estimates for the inputted data. This is a relatively advanced feature of EDGeS. As a starting point a baseline analysis gives useful economic measures for decision makers.

Future versions of EDGeS are planned to have the capability to identify those inputs that are most sensitive to variation—in other words, those that have the most pronounced impact on the relative economic measures.

The remainder of this chapter covers background on the uncertainty distributions provided in EDGeS. Chapter 7 describes the mechanics of entering data related to uncertainty into EDGeS.

6.1 Uncertainty Distributions

In addition to the option for an exact point estimate, EDGeS provides four uncertainty distributions that can be applied to any user-inputted cost, benefit, non-disaster related benefit, or externality. The mechanics of entering this uncertainty information in EDGeS is demonstrated in Chapter 7.

The five uncertainty distribution types included in EDGeS are: 1. Exact, 2. Discrete, 3. Gaussian, 4. Triangular, and 5. Rectangular. These five distributions were chosen because the required input values are fairly straightforward for the user to obtain and they approximate typical uncertainty seen in projects, especially for uncertainties that are most well-unknown without surrounding ambiguity to the user (e.g., budget uncertainties). Each type of uncertainty distribution requires specific user inputs. The uncertainty distributions and their associated required information are noted below.

In the future, versions of EDGeS are planned to incorporate further uncertainty distributions.

6.1.1 Exact Distribution

The exact distribution indicates that the user knows that the point value is the true value for the parameter. If the distribution of uncertainty is completely unknown, it may make sense to use the point estimate value.

6.1.2 Discrete Distribution

The discrete distribution option relates well to the three outcome levels mentioned in the CRPG—routine, design, and extreme. This distribution is not continuous around the point estimate value. The lower, middle, and upper bounds are defined with any one of them being the point value. A probability is also associated with each of the three outcomes, the only requirement being that the sum of the three probabilities equals 100 %.

6.1.3 Gaussian distribution

Gaussian is a common continuous probability distribution. The assumption is that the Gaussian, also known as a 'normal,' distribution is symmetric in EDGeS. The usefulness of this distribution is limited when values lies more than a few standard deviations from the mean. Thus, it is not an appropriate model if the user expects a significant fraction of outliers in the uncertainty distribution. In EDGeS, the point estimate provided by the user is assumed to be the mean value of the Gaussian distribution. The user must then input a scale parameter (standard deviation) value.

Then the probability density function of the Gaussian function is:

$$(1+x)^n = 1 + \frac{1}{\sigma(2\pi)^{1/2}} \exp\left(\frac{-(x-\mu)^2}{2\sigma^2}\right)$$

With location parameter (mean): μ and scale parameter (standard deviation): σ

6.1.4 Rectangular (uniform) distribution

A rectangular distribution is a continuous probability distribution for which all values between the lower bound and the upper bound are assumed to have equal probability. The rectangular distribution is sometimes referred to as a uniform distribution.

The user needs to provide a lower bound and upper bound values; the point estimate value must lie between these two bounds.

Then the distribution function is (x-a) / (b-a) and the probability density function is 1/(b-a), where the location parameter *a*, the lower limit of the range and parameter *b*, is the upper limit of the range.

6.1.5 Triangular distribution

A triangular distribution is a continuous probability distribution. This distribution can be defined to be symmetric or asymmetric. This distribution assumes a probability zero below the lower bound, increasing linearly to the point estimate, decreases linearly to the upper bound, and is zero for all values above the upper bound.

The user needs to provide a lower bound and upper bound values; the point estimate value must lie between these two bounds and is assumed to be the point of maximum likelihood, the "peak," for the distribution.

The triangular cumulative distribution function ($F_X(x)$) is given as:

If $a \le x \le c$ then $F_X(x) = \frac{(x-a)^2}{(b-a)(c-a)}$; If $c \le x \le b$ then $F_X(x) = 1 - \frac{(b-x)^2}{(b-a)(b-c)}$

The cumulative distribution function is zero for all values less than *a* and 1 for all values greater than *c*.

Then the probability density function ($f_X(x)$) is:

If $a \le x < c$ then $f_X(x) = 2 * (x-a)/[(b-a)*(c-a)]$

If $x = c$ then $f_X(x) = 2/(b-a)$

If $c < x \le b$ then $f_X(x) = 2 * (b-x)/[(b-a)*(b-c)]$

With the shape parameter: *c* (the mode), location parameter *a* (the lower limit), and parameter *b* (upper limit).

6.2 Monte Carlo Simulation

Monte Carlo simulations fall under a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results. A Monte Carlo simulation varies a set of key parameters either singly or in combination according to the uncertainty defined around these parameters. As discussed in previous sections, each key parameter is associated with a user-defined probability distribution function. During the Monte Carlo simulation, values are randomly sampled for a given parameter based on the uncertainty distribution for that parameter around its baseline (point estimate) value.

In EDGeS, there is a means for automatically running Monte Carlo simulations. The Monte Carlo simulation technique allows the effects of uncertainty to be analyzed through reference to a derived distribution of project outcome values. For the NPV of each alternative Monte Carlo simulation allows for a relatively accurate upper and lower bound.

A given "seed value" generates a particular sequence; if one uses the same seed the output becomes reproducible—this can be important in refining and correcting the simulation. In the EDGeS application of the Monte Carlo method, simulations continue to be run in sets of 1000 until the means of all parameters do not change from one run to the next within a user-defined tolerance.

7 Entering Data with Uncertainty

In what follows, the term 'item' is used to refer to a cost, externality, benefit, or non-disaster related benefit as is appropriate for the associated page. Uncertainty parameters may be added to most user inputted items after they have been input initially on the appropriate pages, as described in Section 5. If uncertainty is associated with an item and the item is copied, the uncertainty will not be copied. If uncertainty is associated with an item and the item is edited, the uncertainty will be cleared.

7.1 Uncertainty Distributions

Currently, there are five distributions available to the user. The distributions are labeled *Exact*, *Gaussian*, *Triangular*, *Rectangular*, and *Discrete*, as seen in Figure 7.1. There are some differences between the distribution inputs in the *Uncertainties* pages and those in the *Project Information* page, specifically in entering the point estimate value. This section will describe only those inputs associated with the distributions, referring to the point estimate value as the 'assumed amount.' For the *Project Information* page described in Section 7.2, the assumed amount is input in the same location as the uncertainties, and for the *Uncertainties* pages described in Section 7.3 the assumed amount for each item is input on the previous corresponding page. The screenshots from this section are taken from the *Cost Uncertainties* page.

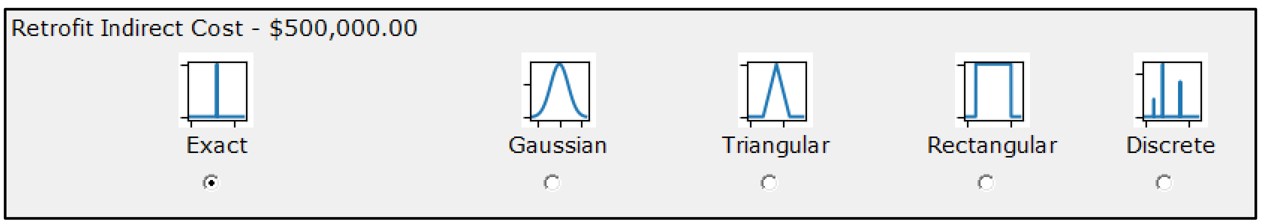


Figure 7.1 The five distributions, with 'Exact' selected

The five distribution types are described here:

1. The 'Exact' distribution signifies no uncertainty, the input always takes the value of the assumed amount. There are no additional inputs associated with the *Exact* distribution, and so in general if this distribution is selected, it will appear as in Figure 7.1. This is the default distribution.

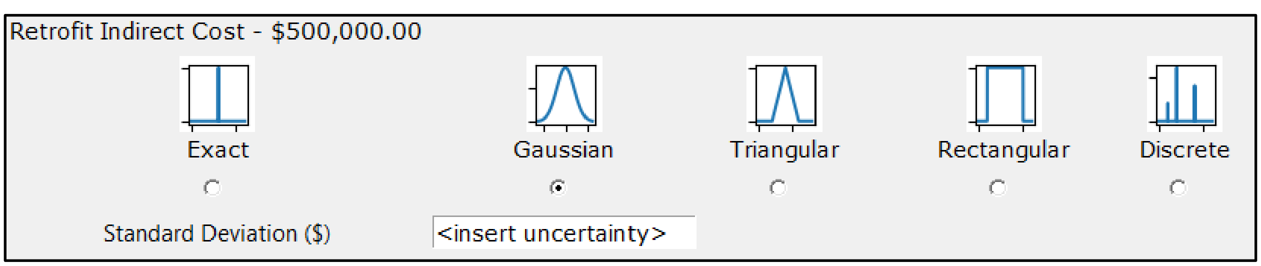


Figure 7.2 The Gaussian Distribution

2. The ‘Gaussian’ distribution is a symmetric Gaussian distribution centered at the assumed amount, with an input for standard deviation, as seen in Figure 7.2. The input for standard deviation must be a number greater than zero. For more information, see Section 6.1.3.

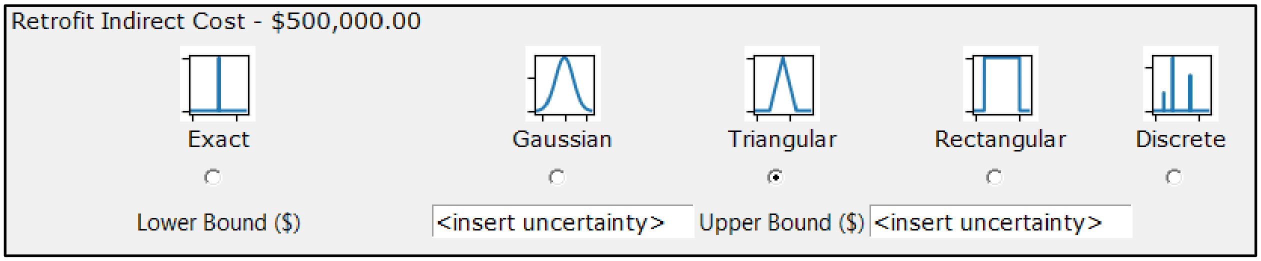


Figure 7.3 The Triangular Distribution

3. The ‘Triangular’ distribution, seen in Figure 7.3, assumes a distribution with probability zero below the input lower bound, increasing linearly to the assumed amount, decreases linearly to the upper bound, and is zero for all values above the upper bound. The input for the lower bound must be a number less than the assumed amount and the input for the upper bound must be a number greater than the assumed amount. For more information, see Section 6.1.5.

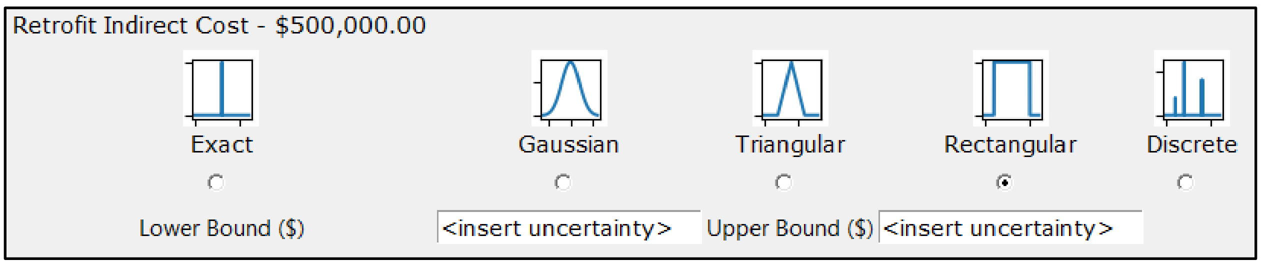


Figure 7.4 The Rectangular Distribution

4. The ‘Rectangular’ distribution, seen in Figure 7.4, assumes an equal probability of all values between the input lower bound and the input upper bound. The input for the lower bound must be a number less than the assumed amount and the input for the upper bound must be a number greater than the assumed amount. The assumed amount is used for point estimate calculations, and does not need to be a center point in the distribution. For more information, see Section 6.1.4.

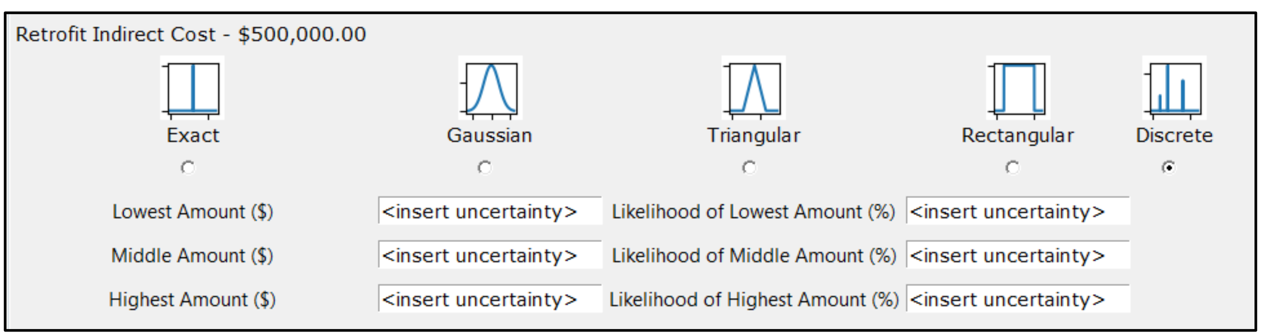


Figure 7.5 The Discrete distribution

5. The ‘Discrete’ distribution, seen in Figure 7.5, assumes that there are only three possible values, the lowest amount with a probability of the likelihood of lowest amount, the middle amount with a probability of the likelihood of middle amount, and the highest amount with a probability of the likelihood of highest amount. The likelihoods must add up to 100. For more information, see Section 6.1.1. For the *Uncertainties* pages, there is an assumed amount, which must be represented as one of the three possible amounts. For the *Project Information* page, the assumed amount is extracted from the discrete distribution information as the most likely amount. If there are two amounts with the same likelihood, EDGeS will choose the lower amount.

7.2 Project Information

As seen in Figure 5.2 with the ‘Exact’ distribution, the *Project Information* page allows for uncertainty in hazard recurrence and magnitude. Unlike the figures in Section 7.1, these include an input field for the assumed amount, as can be seen for ‘Gaussian’ in *Hazard Recurrence* and ‘Triangular’ in *Hazard Magnitude* in Figure 7.6.

For the ‘Discrete’ distribution, seen in Figure 7.7, the first column signifies the values for the appropriate input type (here ‘Hazard Recurrence’) and the second column their relative probabilities.

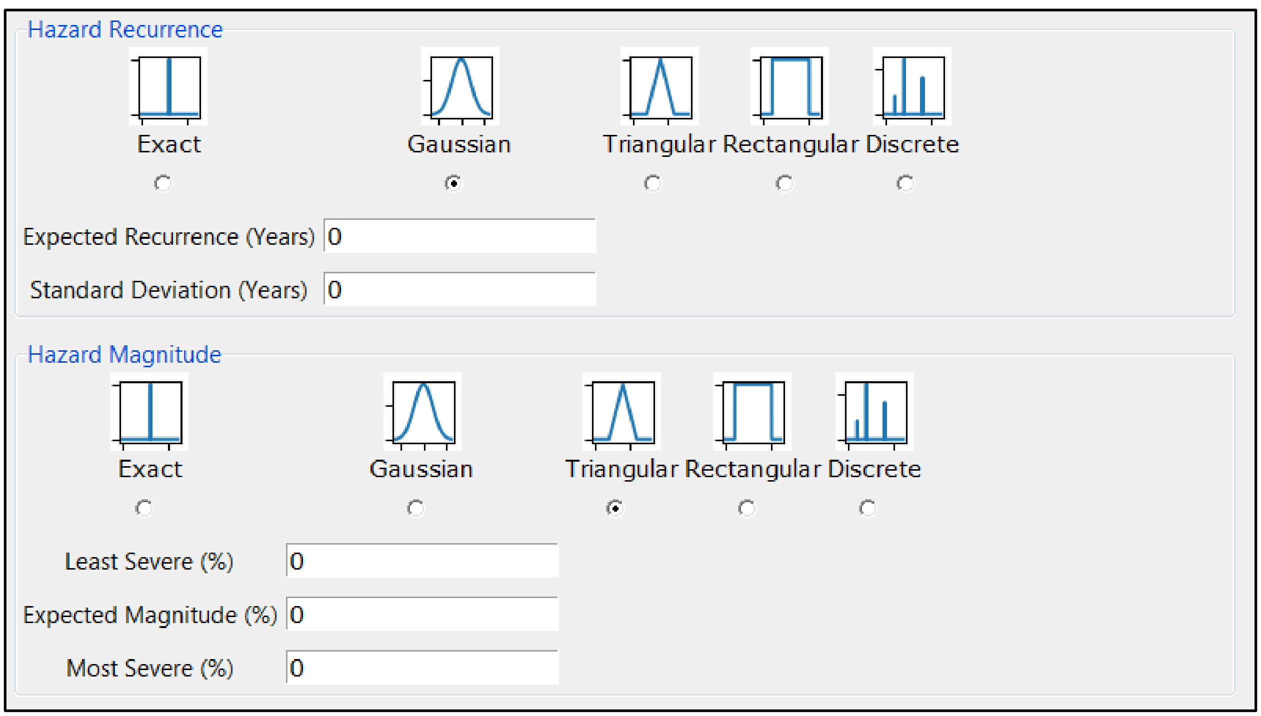


Figure 7.6 Uncertainty in Hazard Recurrence and Magnitude

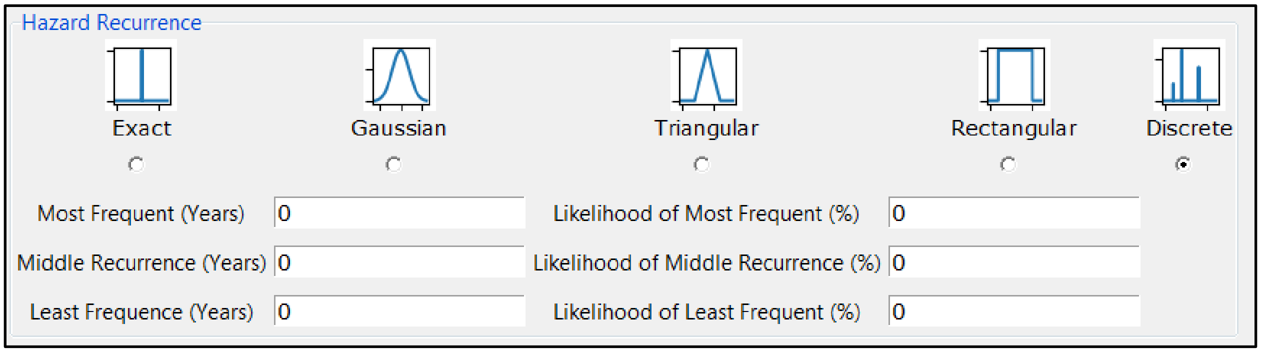


Figure 7.7 Discrete Hazard Recurrence

For ‘Gaussian,’ the assumed amount is set to be the mean, for ‘Triangular,’ the assumed amount is set to be the central value, and for ‘Rectangular,’ the assumed amount is input as the ‘Expected,’ central value.

The assumed amount is extracted from the discrete distribution information as the most likely amount. In the case of two amounts with the same likelihood, EDGeS will assume the lower value.

7.3 Layout of an Uncertainty Page

There are four *Uncertainties* pages, one each associated with costs, benefits, externalities, and non-disaster related benefits. All *Uncertainties* pages are nearly identical, and an example can be seen in Figure 7.9. Though previous examples used *Costs*, this figure uses the *Benefits* page to illustrate the similarity of all *Uncertainties* pages. Pulling up any *Uncertainties* page may take time, dependent on the number of items of that type already saved into the program.

The *Uncertainties* page will list all input items, grouped by their plan. Each item will be designated by its name and amount, as set on the previous page. If a plan has no items of that type, that plan is not listed. This can be seen in the absence of the *Base Plan* in Figure 7.9. The default uncertainty is ‘Exact’ or no uncertainty.

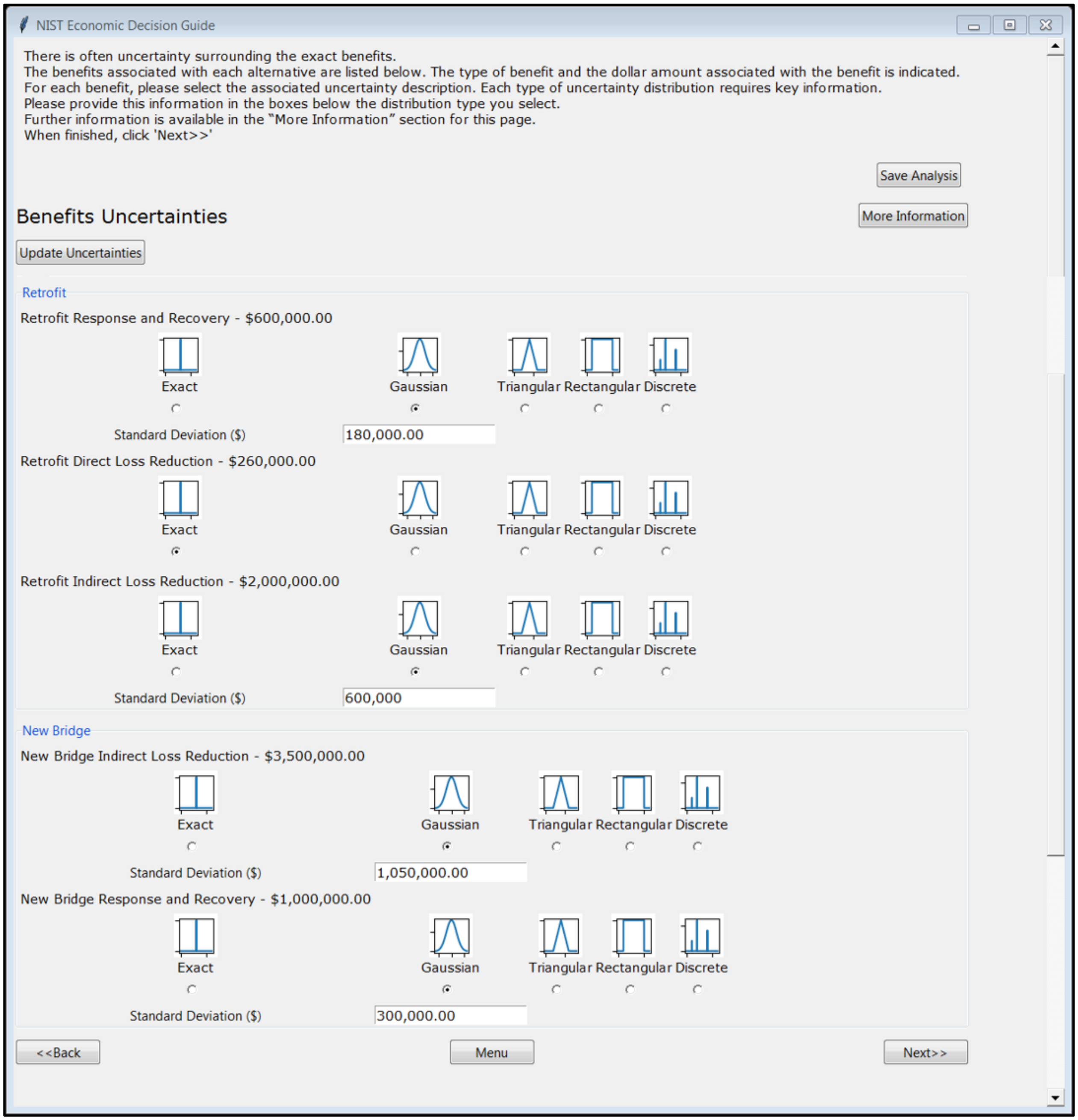


Figure 7.8 The *Benefits Uncertainties* Page

At the top of the page is a header, just as seen in Figure 5.4. Immediately below this header is the *Update Uncertainties* button. To change the available inputs for a given item to those for a specific distribution, the user must use the radio buttons to select the desired distribution and then click *Update Uncertainties*. This will reload the page with the appropriate inputs. *Update Uncertainties* does not check the inputs for validity.

The main portion of the page is the listed items and their uncertainties options. The bottom of the page contains a navigation component as described in Figure 5.11, where each of the navigational buttons will validate the distribution inputs and save the results. Without all distribution inputs being valid, it is impossible to navigate away from this page.

8 Result Analysis and Recommendation of a Cost-Effective Community Resilience Plan

8.1 Running an analysis

Using the *Analysis* button on the *Menu* page or the *Next* button on the *Non-Disaster Related Benefits* page, the user can navigate to the *Analysis Information* page, seen in Figure 8.1.

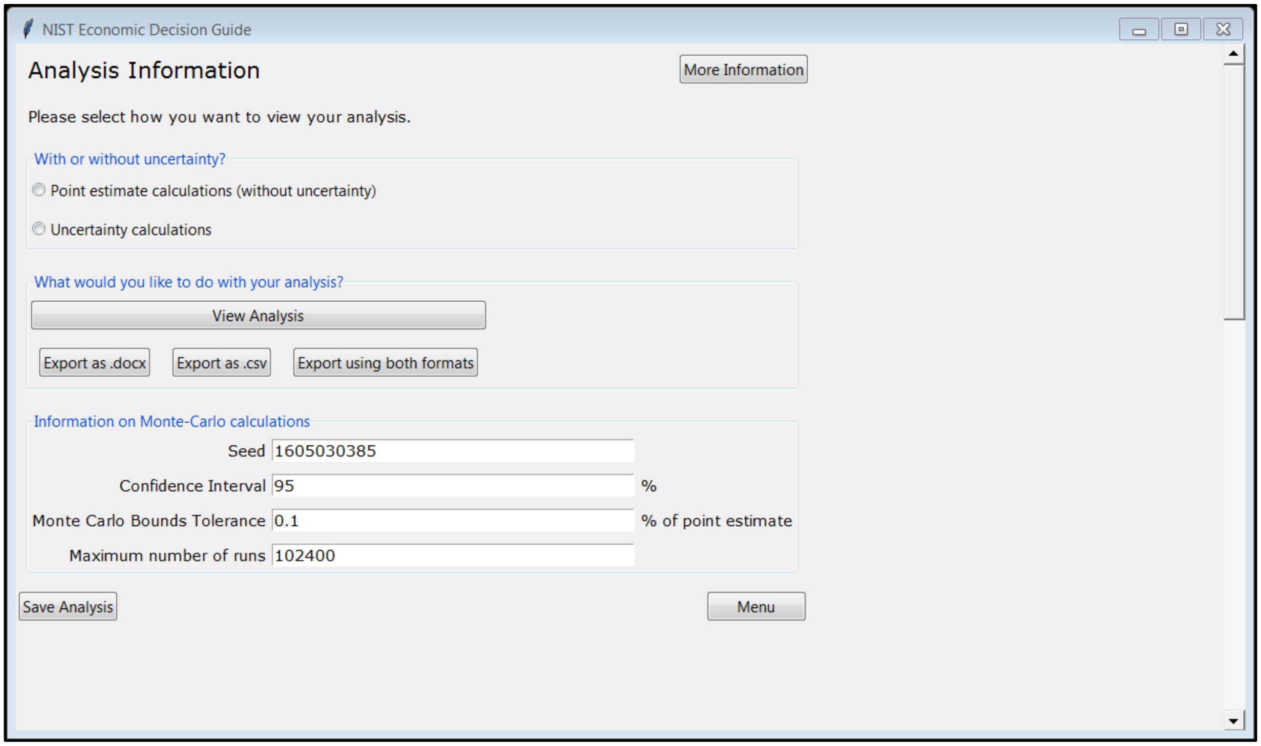
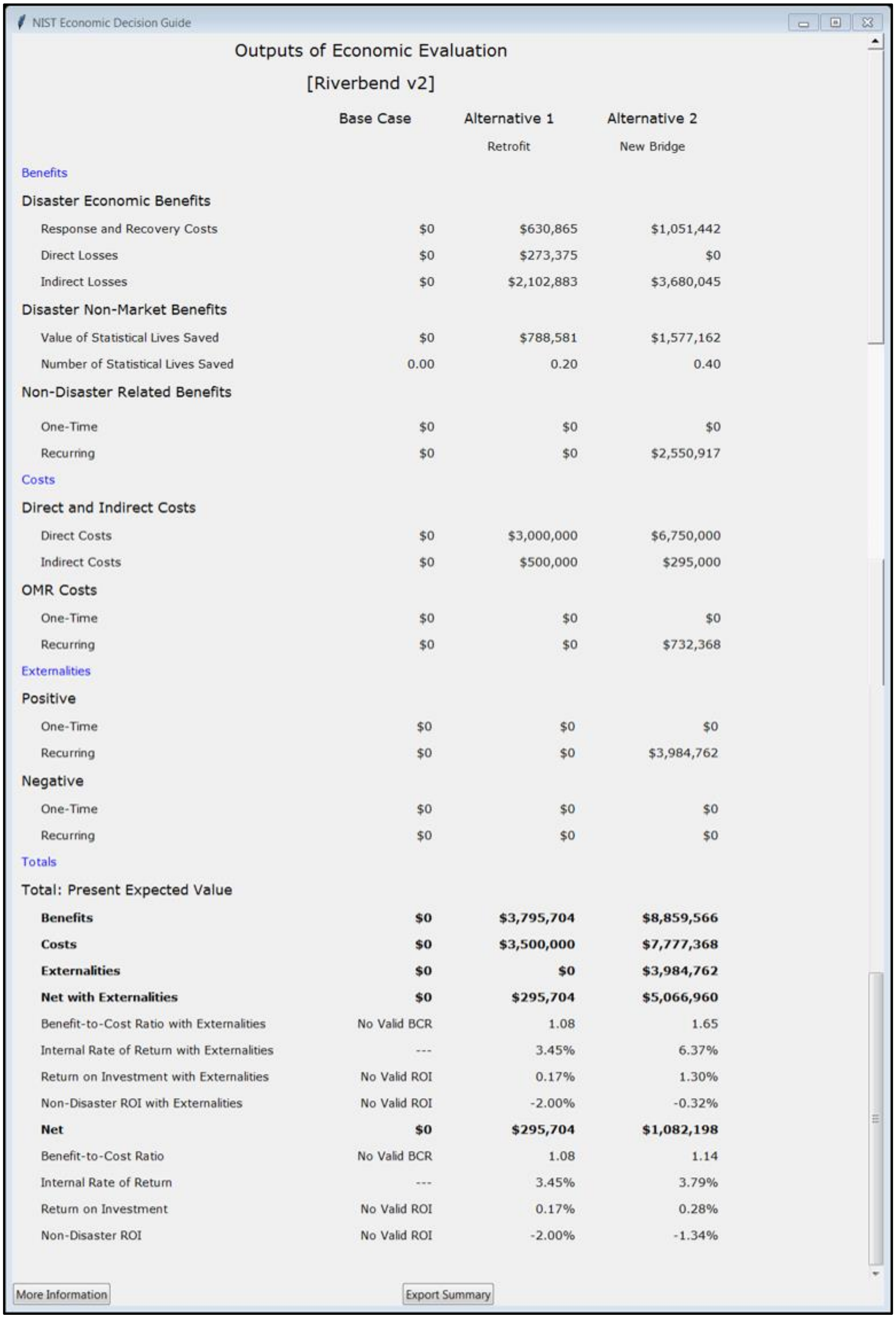


Figure 8.1 The *Analysis Information* page

The *Analysis Information* page allows the user to select how they wish to run and use their analysis. If the user desires to run their analysis without any uncertainty calculations, they must select the radio button 'Point estimate calculations (without uncertainty).' They must then select if they wish to view their results within the program by clicking *View Analysis* or if they wish to export the results without viewing results by clicking *Export as .docx*, *Export as .csv*, or *Export using both formats*, which will export the results as a Microsoft Word document, as a .csv file, or with both formats, respectively. More information on file export is given in Section 8.2.

If the user chooses to view their analysis, they will get a separate window, as seen in Figure 8.2.



	Base Case	Alternative 1 Retrofit	Alternative 2 New Bridge
Benefits			
Disaster Economic Benefits			
Response and Recovery Costs	$0	$630,865	$1,051,442
Direct Losses	$0	$273,375	$0
Indirect Losses	$0	$2,102,883	$3,680,045
Disaster Non-Market Benefits			
Value of Statistical Lives Saved	$0	$788,581	$1,577,162
Number of Statistical Lives Saved	0.00	0.20	0.40
Non-Disaster Related Benefits			
One-Time	$0	$0	$0
Recurring	$0	$0	$2,550,917
Costs			
Direct and Indirect Costs			
Direct Costs	$0	$3,000,000	$6,750,000
Indirect Costs	$0	$500,000	$295,000
OMR Costs			
One-Time	$0	$0	$0
Recurring	$0	$0	$732,368
Externalities			
Positive			
One-Time	$0	$0	$0
Recurring	$0	$0	$3,984,762
Negative			
One-Time	$0	$0	$0
Recurring	$0	$0	$0
Totals			
Total: Present Expected Value			
Benefits	**$0**	**$3,795,704**	**$8,859,566**
Costs	**$0**	**$3,500,000**	**$7,777,368**
Externalities	**$0**	**$0**	**$3,984,762**
Net with Externalities	**$0**	**$295,704**	**$5,066,960**
Benefit-to-Cost Ratio with Externalities	No Valid BCR	1.08	1.65
Internal Rate of Return with Externalities	---	3.45%	6.37%
Return on Investment with Externalities	No Valid ROI	0.17%	1.30%
Non-Disaster ROI with Externalities	No Valid ROI	-2.00%	-0.32%
Net	**$0**	**$295,704**	**$1,082,198**
Benefit-to-Cost Ratio	No Valid BCR	1.08	1.14
Internal Rate of Return	---	3.45%	3.79%
Return on Investment	No Valid ROI	0.17%	0.28%
Non-Disaster ROI	No Valid ROI	-2.00%	-1.34%

Figure 8.2 Viewing analysis without uncertainties

This analysis is done using only the point estimate values. Externalities are included in *Net with Externalities* and the *with Externalities* measures below it. If there are no externalities in the project, this section will not appear. From this page, the user may click on *Export Summary* and export these results through the same methods that are available on the *Analysis Information* page. Having run this page does not exclude the user from returning to the *Analysis Information* page and making changes in their analysis or running the project with uncertainties.

If the user wishes to run uncertainty calculations, they must select the radio button labeled 'Uncertainty calculations.' They must then select if they wish to view their results within the program by clicking *View Analysis* or if they wish to export the results without viewing results by clicking *Export as .docx*, *Export as .csv*, or *Export using both formats*, which will export the results as a Microsoft word document, as a .csv file, or with both formats, respectively. More information on file export is given in Section 8.2.

The user may customize their Monte-Carlo simulation using: 1. the *Seed*, 2. the *Prediction Interval*, 3. the *Monte-Carlo Bounds Tolerance*, and 4. the *Maximum number of runs* inputs at the bottom of the analysis information page. The seed will be unique each time EDGeS is started and is not saved with the analysis. If the user saves an export file, the seed used to produce those results is printed near the top of the file, and the user may input this seed manually to reproduce results.

Monte-Carlo simulations will continue to run in sets of 1000 until the means of *Total Costs*, *Total Benefits*, *Net*, and *Net with Externalities* do not change from one set to the next by more than a prescribed tolerance. This prescribed tolerance is set uniquely for each value, and is equal to the Monte-Carlo bounds tolerance percentage of the point estimate. For the Riverbend example with a 0.1 % tolerance, the program will run Monte-Carlo simulations of Plan 1 until the mean of the benefits measure changes by less than 0.1 % of 3 795 704 USD (3796 USD), the mean of the costs measure changes by less than 0.1 % of 3 500 000 USD (3500 USD), the mean of the net measure changes by less than 0.1 % of 295 704 USD (296 USD), and the mean of the net with externalities measure changes by less than 0.1 % of 295 704 USD (296 USD).

While the Monte-Carlo simulations are running, the program will pop-up a message to inform the user that these simulations are running, as seen in Figure 8.3. This pop-up message will close itself when the simulations are done running and the user should not close it themselves, nor should the user take this time to do other actions within EDGeS. The user may use other programs in the foreground while the simulations are running without stopping the run of the analysis.

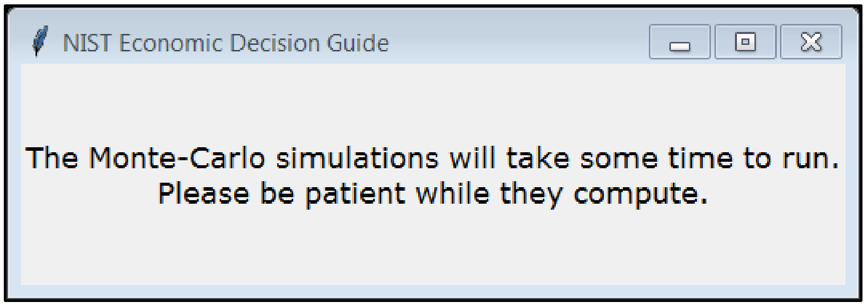


Figure 8.3 Running Monte-Carlo message

If the user runs the Monte-Carlo simulations for a file export and then desires another action, those simulations will be run again. If the user chooses to view the analysis with uncertainties, as seen in Figure 8.4, they may select *Export Summary* to export the results directly without the need to re-run the simulations.

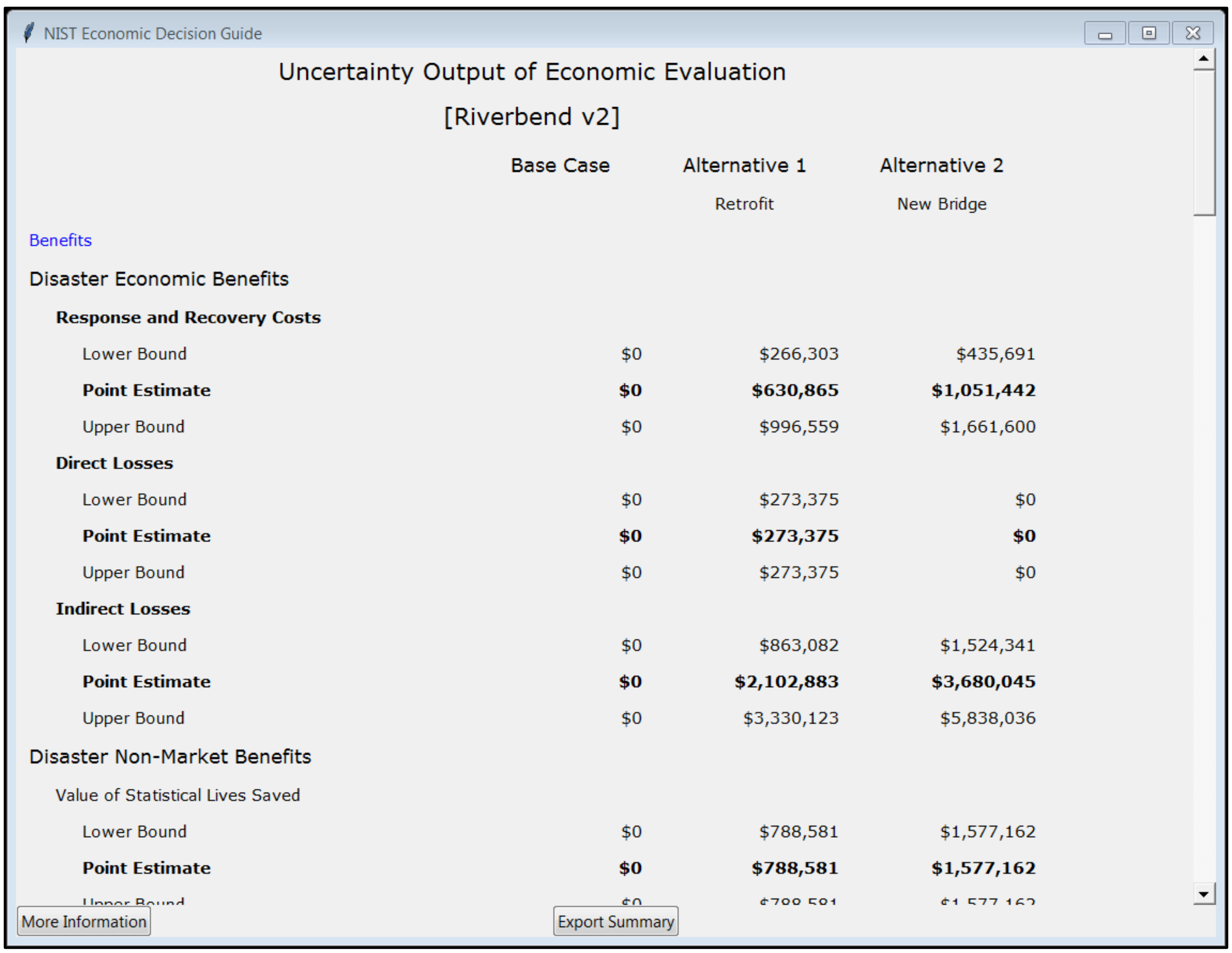


Figure 8.4 Analysis with uncertainties

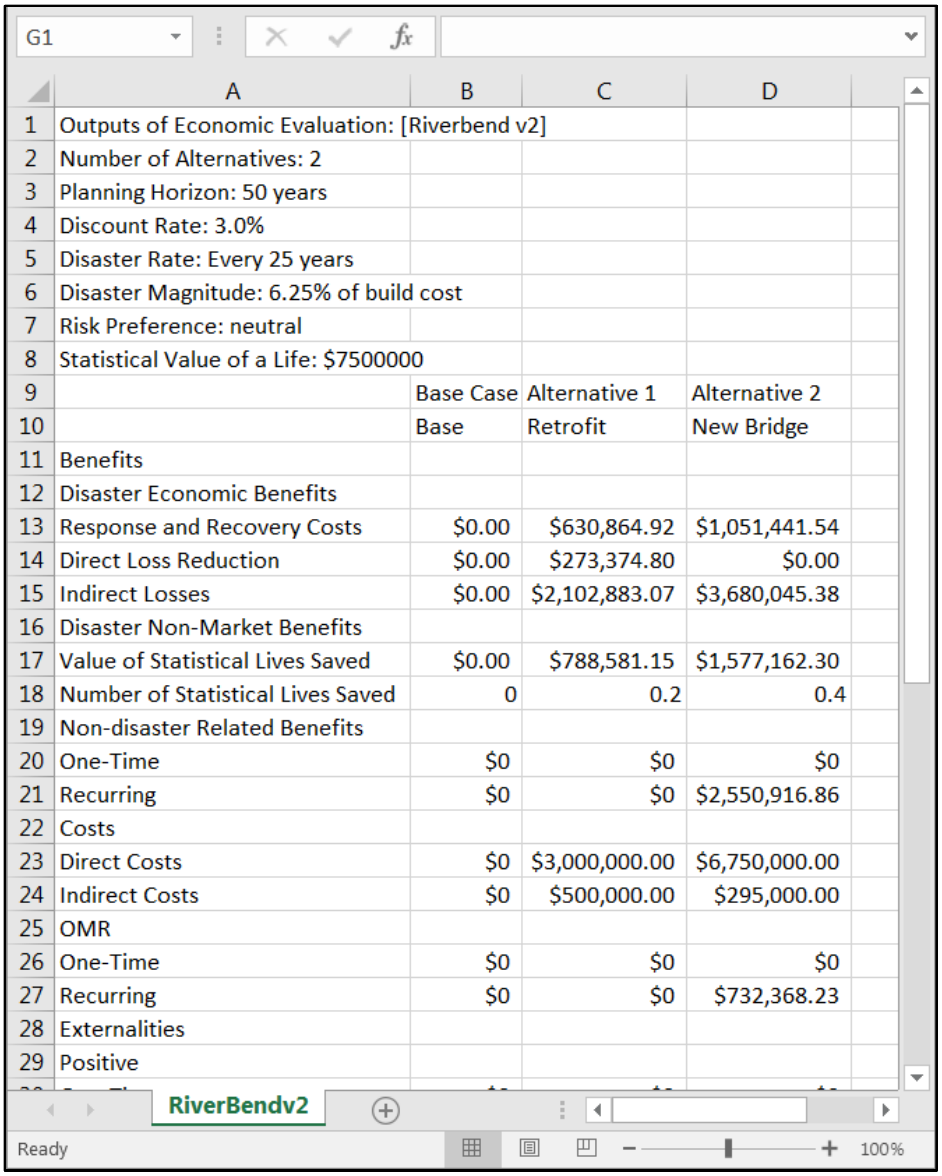
Viewing the analysis results with uncertainties includes all point estimate calculations, along with a lower and upper bound for every reported metric seen in Figure 8.4. Figure 8.4 shows only a subset of the full page with uncertainties.

8.2 Program exporting capabilities

In addition to viewing the results within the program, the user may choose to export their analysis either as a .csv file or as a .docx file, both with or without uncertainty calculations.

8.2.1 Comma Separated Value (.csv) File

The .csv file is designed to open cleanly in Microsoft Excel or any similar program, as can be seen in Figure 8.5. The export without uncertainties gives the same information that is found on the analysis results page within the program in addition to some of the information saved on the project information page, including planning horizon, discount rate, hazard rate and magnitude, risk preference, and the statistical value of a life. If the hazard magnitude or risk preference are left blank on the *Project Information* page, the blank field is not included.



	A	B	C	D
1	Outputs of Economic Evaluation: [Riverbend v2]			
2	Number of Alternatives: 2			
3	Planning Horizon: 50 years			
4	Discount Rate: 3.0%			
5	Disaster Rate: Every 25 years			
6	Disaster Magnitude: 6.25% of build cost			
7	Risk Preference: neutral			
8	Statistical Value of a Life: $7500000			
9		Base Case	Alternative 1	Alternative 2
10		Base	Retrofit	New Bridge
11	Benefits			
12	Disaster Economic Benefits			
13	Response and Recovery Costs	$0.00	$630,864.92	$1,051,441.54
14	Direct Loss Reduction	$0.00	$273,374.80	$0.00
15	Indirect Losses	$0.00	$2,102,883.07	$3,680,045.38
16	Disaster Non-Market Benefits			
17	Value of Statistical Lives Saved	$0.00	$788,581.15	$1,577,162.30
18	Number of Statistical Lives Saved	0	0.2	0.4
19	Non-disaster Related Benefits			
20	One-Time	$0	$0	$0
21	Recurring	$0	$0	$2,550,916.86
22	Costs			
23	Direct Costs	$0	$3,000,000.00	$6,750,000.00
24	Indirect Costs	$0	$500,000.00	$295,000.00
25	OMR			
26	One-Time	$0	$0	$0
27	Recurring	$0	$0	$732,368.23
28	Externalities			
29	Positive			

Figure 8.5 .csv export without uncertainties

Similarly, the export file with uncertainties gives the same information as can be found in the analysis results with uncertainties, as can be seen in Figure 8.6. The export file with uncertainties includes the values from the analysis information page that guided the Monte-Carlo inputs, the number of simulations run before convergence for each plan, and the information from the Project Information page present on the export file without uncertainties.

	A	B	C	D	E	F	G	H	I	J
1	Outputs of Economic Evaluation: [Riverbend v2]									
2	NOTE: All bounds on uncertainties are given with a 95.0% confidence interval. The number of runs was determined with a 0.1% tolerance.									
3	For Base (Alternative 0) 1000 Monte-Carlo simulations were run.									
4	For Retrofit (Alternative 1) 13000 Monte-Carlo simulations were run.									
5	For New Bridge (Alternative 2) 12000 Monte-Carlo simulations were run.									
6	The random number seed for these runs was 1622842854.									
7	Number of Alternatives: 2									
8	Planning Horizon: 50 years									
9	Discount Rate: 3.0%									
10	Disaster Rate: Every 25 years									
11	Disaster Magnitude: 6.25% of build cost									
12	Risk Preference: neutral									
13	Statistical Value of a Life: $7500000									
14		Base Case	Lower Bound	Upper Bound	Alternative 1	Lower Bound	Upper Bound	Alternative 2	Lower Bound	Upper Bound
15		Base			Retrofit			New Bridge		
16	Benefits									
17	Disaster Economic Benefits									
18	Response and Recovery Costs	$0.00	$0.00	$0.00	$630,864.92	$266,303.04	$996,558.87	$1,051,441.54	$435,690.99	$1,661,600.21
19	Direct Loss Reduction	$0.00	$0.00	$0.00	$273,374.80	$273,374.80	$273,374.80	$0.00	$0.00	$0.00
20	Indirect Losses	$0.00	$0.00	$0.00	$2,102,883.07	$863,081.59	$3,330,123.40	$3,680,045.38	$1,524,341.48	$5,838,036.19
21	Disaster Non-Market Benefits									
22	Value of Statistical Lives Saved	$0.00	$0.00	$0.00	$788,581.15	$788,581.15	$788,581.15	$1,577,162.30	$1,577,162.30	$1,577,162.30
23	Number of Statistical Lives Saved	0	0	0	0.2	0.2	0.2	0.4	0.4	0.4
24	Non-disaster Related Benefits									
25	One-Time	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	Recurring	$0	$0	$0	$0	$0	$0	$2,550,916.86	$1,929,523.97	$2,831,998.26
27	Costs									
28	Direct Costs	$0	$0	$0	$3,000,000.00	$2,909,101.10	$3,691,166.05	$6,750,000.00	$6,666,973.27	$7,908,610.33
29	Indirect Costs	$0	$0	$0	$500,000.00	$488,357.79	$708,253.30	$295,000.00	$291,283.37	$344,247.98

RiverBendv2 MC

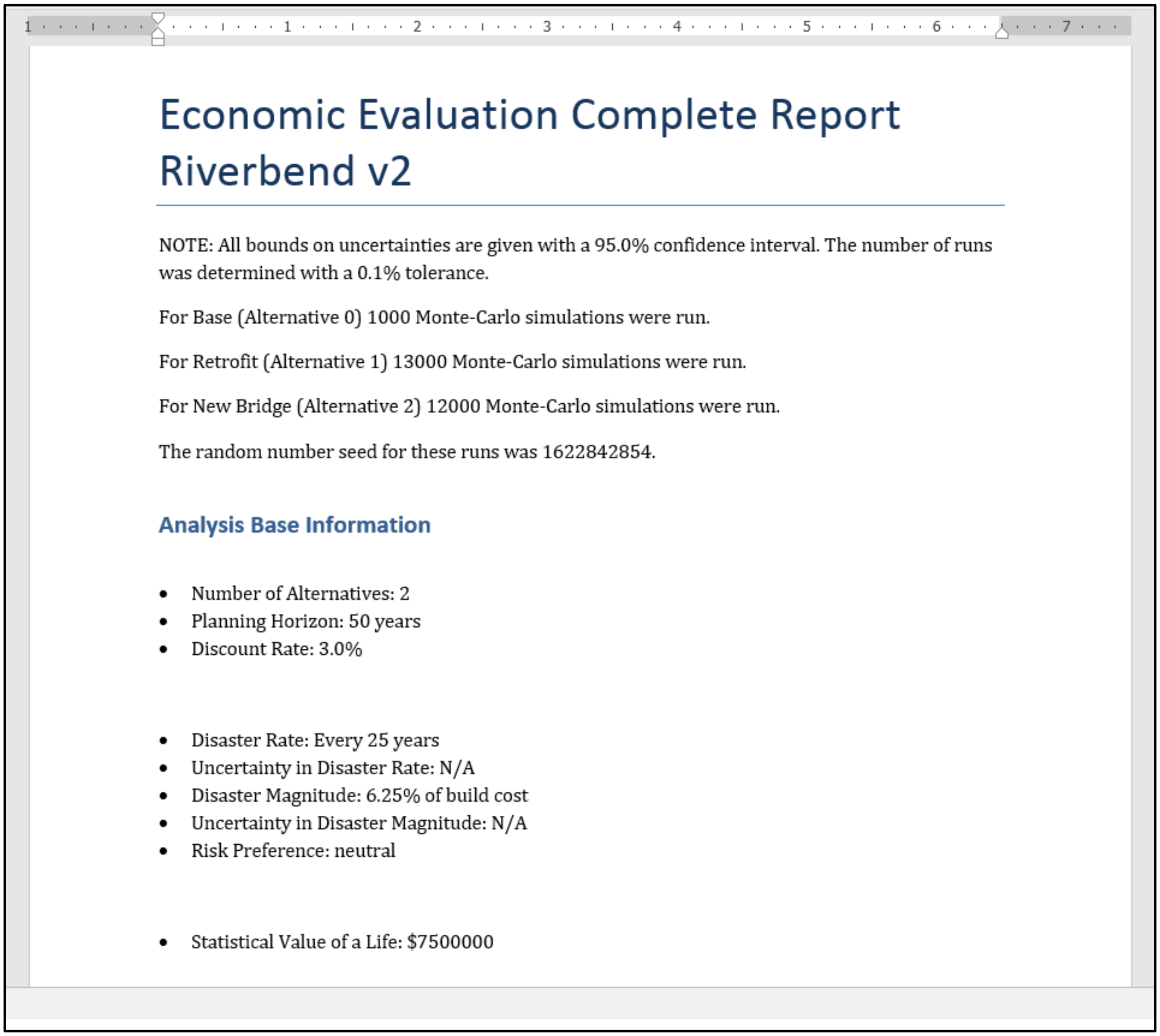
Ready

Figure 8.6 .csv export with uncertainties

The .csv export files are designed to allow the user to save the results of their analysis in a way that the results are both clear and reproducible. Their ease of access using Excel or similar spreadsheet programs makes it possible for the user to easily access these results in doing any calculations of their own.

8.2.2 Microsoft Word file

The Word file consists of three parts. The first part, seen in Figure 8.7, gives the same set of information as at the top of the .csv files. This is where the assumptions on the planning horizon, discount rate, hazard rate and magnitude, risk preference, and statistical value of a life for the analysis can be found. If the hazard magnitude or risk preference are left blank on the *Project Information* page, the blank field is not included. If uncertainty is included, this section also has the confidence interval, the tolerance, the number of Monte-Carlo simulations run, the random number seed, and any uncertainty given in the hazard rate and magnitudes.



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NOTE: All bounds on uncertainties are given with a 95.0% confidence interval. The number of runs was determined with a 0.1% tolerance.

For Base (Alternative 0) 1000 Monte-Carlo simulations were run.

For Retrofit (Alternative 1) 13000 Monte-Carlo simulations were run.

For New Bridge (Alternative 2) 12000 Monte-Carlo simulations were run.

The random number seed for these runs was 1622842854.

Analysis Base Information

- Number of Alternatives: 2
- Planning Horizon: 50 years
- Discount Rate: 3.0%

- Disaster Rate: Every 25 years
- Uncertainty in Disaster Rate: N/A
- Disaster Magnitude: 6.25% of build cost
- Uncertainty in Disaster Magnitude: N/A
- Risk Preference: neutral

- Statistical Value of a Life: $7500000

Figure 8.7 First page of Word export with uncertainties

The next part gives a summary table, seen without uncertainties in Figure 8.8, which gives the larger perspective of the results. This table consists of total benefits, total costs, net, BCR, IRR, ROI, and Non-Disaster ROI.

Summary (with Externalities)

Plan Title	Total Benefits ($)	Total Costs ($)	Net ($)	BCR	IRR (%)	ROI (%)	Non-Disaster ROI (%)
Base	0	0	0	No Valid BCR	---	No Valid ROI	No Valid ROI
Retrofit	3,795,704	3,500,000	295,704	1.08	3.45	0.17	-2.00
New Bridge	12,844,328	7,777,368	5,066,960	1.65	6.37	1.30	-0.32

Figure 8.8 Word export summary table

For plans without uncertainties defined, the totals are given in columns and the plans are listed down rows. There are two Summary tables, one with externalities included in all the results, including totals benefits and costs, and the other without externalities. If the project contains no externalities, only the table without externalities will be included. If uncertainties are included, the totals and their bounds are in rows and the plans are listed across the columns. As can be seen in Figure 8.9, bounds for each total are given in the row immediately below the total, in the format of (lower bound; upper bound).

Summary

	Base	Retrofit	New Bridge
Total Benefits ($)	0	3,795,704	8,859,566
(Lower Bound, Upper Bound) ($)	(0; 0)	(2,515,918; 5,091,539)	(6,462,843; 11,034,492)
Total Costs ($)	0	3,500,000	7,777,368
(Lower Bound, Upper Bound) ($)	(0; 0)	(3,452,587; 4,279,232)	(7,709,895; 8,985,296)

Figure 8.9 Word export uncertainties piece of summary table

The third piece of the export file is a detailed list of all aspects of each plan, grouped by plan, then type. The aspects are presented in the order Fatalities Averted, Disaster-Related Benefits, Resilience Dividend (Non-Disaster Related Benefits), Costs, and Externalities. Fatalities Averted gives the number of statistical lives saved, the value of statistical lives saved, and a description if a description is given in the program. The rest are presented in tables. Each table contains all information necessary to exactly reproduce that section in the program and the intermediate sums presented in the analysis results viewed within the program. Below the table is presented uncertainty for each item, if the Word export is to include uncertainty and the item has an uncertainty that is not *Exact*, and the description for the item, assuming the description is not left blank.

Costs

Title	Start Year	Recurrence (Years)	Amount ($)	Effective Present Value ($)
Direct Costs				3,000,000
Retrofit Direct Cost	Start-Up	N/A	3,000,000	3,000,000
Indirect Costs				500,000
Retrofit Indirect Cost	Start-Up	N/A	500,000	500,000
OMR Costs: One-Time				0
OMR Costs: Recurring				0
Total				3,500,000

Retrofit Indirect Cost: Triangular distribution with a min of 475000.00 and a max of 750000.00

Retrofit Indirect Cost: Indirect costs for retrofitting the old bridge. This includes indirect costs of the retrofit actions as well as costs associated with diverted traffic.

Retrofit Direct Cost: Triangular distribution with a min of 2850000.00 and a max of 3840000.00

Retrofit Direct Cost: Cost to retrofit the old bridge.

Figure 8.10 Example Costs table with uncertainty

As an example, Figure 8.10 gives the Costs table for the first plan of the Riverbend example discussed in Section 3. The first row gives the *Direct Costs*. This row is the total effective present value of all direct costs associated with this plan. Immediately below that is the only direct cost given, along with the amount and calculated effective present value. If there were several costs, they would be listed here. The following row is *Indirect Costs*, which gives the sum of all indirect costs associated with this plan and the individual indirect costs are listed below. For this example, there is only one. This is followed by the *OMR Costs: One-Time* and *OMR Costs: Recurring* rows. These rows also give the effective present value of costs under this plan for each category. In this case, there are none.

Any associated uncertainties and descriptions are listed immediately below the table. Each uncertainty description and/or cost description is preceded by the title of the plan with which it is associated. Here it can be seen that both the 'Retrofit Indirect Cost' and the 'Retrofit Direct Cost' items have an uncertainty in the form of a triangular distribution. If a cost had no uncertainty, no uncertainty information would be listed. The description associated with each cost can also be seen. If a cost were to have no description, no description would be listed.

The Word export file is designed to allow both a quick overview of the results at the beginning, and a detailed breakdown of each input. This allows the user to have readily available any necessary summary output and to be able to easily locate any individual inputs for further review.

8.3 Interpreting Results

Inputting the values from Table 3.2 and Table 3.3 into EDGeS according to the previous sections, and running the analysis using point estimates, yields Table 8.1. Red dollar values in parentheses indicate a negative value for all tables in this section.

There are two *NPV* s given in the output, *with* externalities and *without* (present expected values are given for costs and externalities as well). Based on the *NPV* without externalities the *Retrofit* is preferable over the *New Bridge* as it has a higher *NPV*. In this case both options have a positive *NPV* meaning both represent net savings based on their discounted cash flows, however that may not always be the case. If the project is optional and both *NPV*s are negative, it may be that the best option economically is the implicit third alternative of doing nothing. Whether doing nothing has any political ramifications that may compel action is also a consideration, though not necessarily an economic one.

The inclusion of externalities is not an obvious decision in all cases. Although these externalities represent benefits, they are accrued by parties outside of the decision makers, and may never materialize as actual cash flows. Another difficulty is where to cut off external parties[20]. The reduction in pollution could also decrease costs at a water treatment plant downstream for instance. Where the boundaries should be set for externalities needs to be seriously considered if external parties are to be included. The final decision in this case is the same regardless of the inclusion of externalities or which economic indicators are used; the *New Bridge* alternative is the preferred option[21].

[20] In this context "external" means outside of the parties whose costs are internalized in the analysis.

[21] Note that *preferred* here does not necessarily mean *best*. Every decision is made under risk. The goal of any analysis where values are estimated, uncertain, or knowledge is incomplete should be to make the best decision given the information available, which may not necessarily be the best decision objectively.

Table 8.1 Results from EDGeS analysis using point estimates

	Retrofit	New Bridge
Disaster Economic Benefits		
Response and Recovery Costs	$630 865	$1 051 442
Direct Loss Reduction	$273 375	$0
Indirect Losses	$2 102 883	$3 680 045
Disaster Non-Market Benefits		
Value of Statistical Lives Saved	$788 581	$1 577 162
Number of Statistical Lives Saved	0.2	0.4
Non-disaster Related Benefits		
One-Time	$0	$0
Recurring	$0	$2 550 917
Costs		
Direct Costs	$3 000 000	$6 750 000
Indirect Costs	$500 000	$295 000
OMR		
One-Time	$0	$0
Recurring	$0	$732 368
Externalities		
Positive		
One-Time	$0	$0
Recurring	$0	$3 984 762
Negative		
One-Time	$0	$0
Recurring	$0	$0
Present Expected Value		
Benefits	$3 795 704	$8 859 566
Costs	$3 500 000	$7 777 368
Externalities	$0	$3 984 762
With Externalities		
Net (NPV)	$295 704	$5 066 960
Benefit-to-Cost Ratio	1.08	1.65
Internal Rate of Return (%)	3.45	6.37
Return on Investment (%)	0.17	1.30
Non-Disaster ROI (%)	-2.00	-0.32
Without Externalities		
Net (NPV)	$295 704	$1 082 198
Benefit-to-Cost Ratio	1.08	1.14
Internal Rate of Return (%)	3.45	3.79
Return on Investment (%)	0.17	0.28
Non-Disaster ROI (%)	-2.00	-1.34

If the analysis is run under uncertainty, Table 8.2 and Table 8.3 are obtained. *Lower* and *Upper* bounds represent those values required for a 95 % prediction interval, i.e. 95 % confidence interval on the output values from the simulation. They are not confidence intervals on the mean. The point estimate in not the mean of the simulations, but the result of the point estimate calculations summarized in Table 8.1.

Adding uncertainty complicates interpretation. While the additional information more accurately reflects the potential range of outcomes, it also means that choices must be made balancing risk and desired outcome. An alternative with a higher mean *NPV* but a large range of uncertainty may not be as attractive as an alternative with a lower *NPV* but a smaller range of uncertainty.

Table 8.2 Intermediate Results from EDGeS under uncertainty[22]

	Retrofit			New Bridge		
	PE	Lower Bound	Upper Bound	PE	Lower Bound	Upper Bound
Disaster Economic Benefits						
Response and Recovery Costs	$630 865	$258 965	$1 000 580	$1 051 442	$455 623	$1 668 008
Direct Loss Reduction	$273 375	$112 355	$429 260	$0	$0	$0
Indirect Losses	$2 102 883	$856 638	$3 331 145	$3 680 045	$1 468 572	$5 812 145
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	$788 581	$788 581	$788 581	$1 577 162	$1 577 162	$1 577 162
Number of Statistical Lives Saved	0.20	0.20	0.20	0.40	0.40	0.40
Non-disaster Related Benefits						
One-Time	$0	$0	$0	$0	$0	$0
Recurring	$0	$0	$0	$2 550 917	$1 941 394	$2 828 638
Costs						
Direct Costs	$3 000 000	$2 910 188	$3 691 765	$6 750 000	$6 658 530	$7 906 460
Indirect Costs	$500 000	$488 429	$708 031	$295 000	$290 961	$343 936
OMR						
One-Time	$0	$0	$0	$0	$0	$0
Recurring	$0	$0	$0	$732 368	$649 642	$859 790
Externalities						
Positive						
One-Time	$0	$0	$0	$0	$0	$0
Recurring	$0	$0	$0	$3 984 762	$3 231 144	$4 767 689
Negative						
One-Time	$0	$0	$0	$0	$0	$0
Recurring	$0	$0	$0	$0	$0	$0

[22] These values will differ based on the selected “Seed” and “Monte Carlo Bounds Tolerance” values on the “Analysis Information” pages

Table 8.3 Economic Indicators from EDGeS under uncertainty[23]

	Retrofit			New Bridge		
	PE	Lower Bound	Upper Bound	PE	Lower Bound	Upper Bound
Present Expected Value						
Benefits	$3 795 704	$2 486 168	$5 097 075	$8 859 566	$6 426 767	$11 035 205
Costs	$3 500 000	$3 454 379	$4 283 494	$7 777 368	$7 701 736	$8 991 533
Externalities	$0	$0	$0	$3 984 762	$3 231 144	$4 767 689
With Externalities						
Net (NPV)	$295 704	($1 402 227)	$1 358 079	$5 066 960	$1 861 184	$6 888 628
Benefit-to-Cost Ratio	1.08	0.64	1.38	1.65	1.23	1.86
Internal Rate of Return (%)	3.45	0.86	4.88	6.37	4.21	7.32
Return on Investment (%)	0.17	-0.71	0.76	1.30	0.45	1.72
Non-Disaster ROI (%)	-2.00	-2.00	-2.00	-0.32	-0.72	-0.19
Without Externalities						
Net (NPV)	$295 704	($1 402 227)	$1 358 079	$1 082 198	($1 883 739)	$2 826 110
Benefit-to-Cost Ratio	1.08	0.64	1.38	1.14	0.78	1.35
Internal Rate of Return (%)	3.45	0.86	4.88	3.79	1.58	4.92
Return on Investment (%)	0.17	-0.71	0.76	0.28	-0.43	0.71
Non-Disaster ROI (%)	-2.00	-2.00	-2.00	-1.34	-1.53	-1.30

Looking at the Riverbend analysis, while the point estimates for the *NPV* without externalities for the *New Bridge* is higher, its lower bound is less than the lower bound of the retrofit. Considering the higher point estimate and upper bound for the alternative, the indication is that there is a larger amount of uncertainty in the *New Bridge* option, due to the increased construction costs and their associated uncertainties. In this case the decision becomes difficult and may depend on the risk preference of the decision maker, or require further analysis.[24] The other economic indicators are not useful in this instance either.

In this example, if externalities are included the decision once again becomes trivial. The *NPV* with externalities is consistently higher in its 95 % prediction interval and does not become negative in that range. In the presence of the assumed externalities, the *New Bridge* is the best option.

[23] These values will differ based on the selected "Seed" and "Monte Carlo Bounds Tolerance" values on the "Analysis Information" pages

[24] Future versions will also report the mean of the simulations, allowing for a better understanding of the central tendencies and overall skew of the distribution of simulated results. Histogram representations of the simulated results are also being examined.

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Appendix A. Detailed Tutorial

This tutorial on using EDGeS will walk through the creation of the Riverbend infrastructure resilience project described in Section 3.2.

To see the completed project, load 'Riverbend v2_withNewRoad.csv' into EDGeS as described in Section 4.1. This tutorial will focus on building that completed file from scratch. To begin, open the program. You will see the screen shown in Figure A.1. Select 'Start new analysis' and click *OK*. The *Project Information* page will come up.

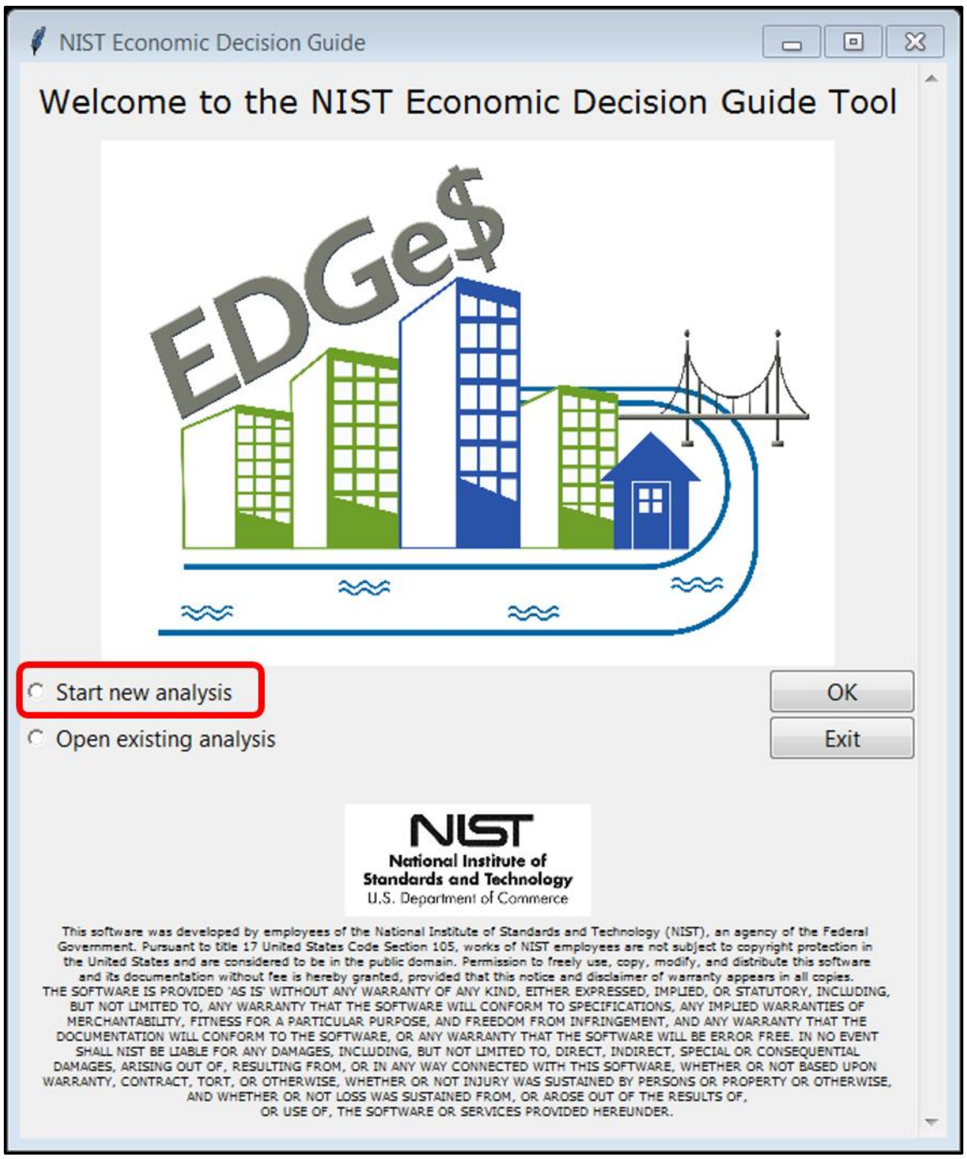


Figure A.1 EDGeS Opening page

A.1. Entering Project Information

To fill out the *Project Information* page, first gather the necessary information. For this example, the gathered information is summarized in Table A.1.

Table A.1 Required project information

Required Information	Example specific data
Project Name	Riverbend
Planning Horizon	50 years
Number of Alternative Plans	2
Name of Alternative Plan 1	Retrofit
Name of Alternative Plan 2	New Bridge
Real Discount Rate	3 %
Hazard Recurrence Rate	Every 25 years
Hazard Recurrence Uncertainty Distribution	Exact

Once the information is prepared and gathered, the *Project Information* page, may be completed.

For what follows, every field is referred to by name followed by the letter reference from Figure A.2. Enter the project name in the *Name* field (A) where it says '<enter project name>.' The project name will be on the export files, so this entry should be clear and concise. Enter the planning horizon, in number of years, in the *Planning Horizon* field (B) where it says '<enter number of years for analysis>.'

From the *Number of Alternative Plans* dropdown menu (C), select the number of alternative plans, up to six. You may also type in the number of plans, but cannot go above six. Once the number of alternative plans has been selected, the corresponding number of *Alternative name* fields are available.

Next to *Alternative 1*, enter the name of alternative plan 1 where it says '<enter plan name>.' Next to *Alternative 2*, enter the name of alternative plan 2 where it says '<enter plan name>.'

Since this plan's real discount rate is not the default 5 %, in the *Discount Rate* field (D), enter the real discount rate of 3 %.

Note that for this example, *Hazard Recurrence* has no uncertainty. The default uncertainty distribution is *Exact*, so no changes need to be made. Before setting the hazard recurrence, experiment with the different distributions offered and spend some time getting comfortable with the inputs required for each distribution. The uncertainty is labeled F in Figure A.2. Return the uncertainty to *Exact* and enter the hazard recurrence rate in the field next to *Recurrence (Years)* (G). Hazard recurrence refers to how frequently the hazard will return.

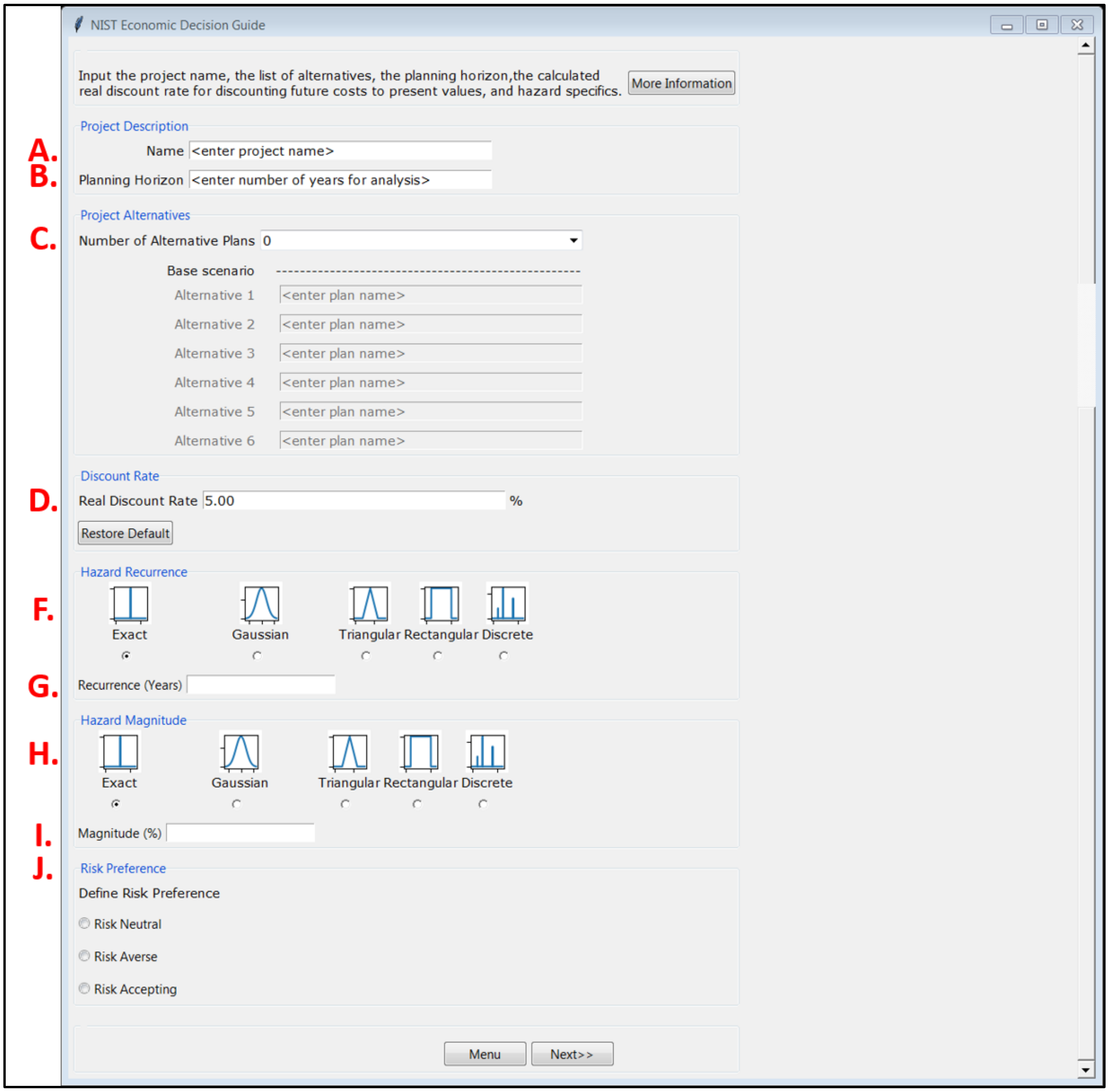


Figure A.2 Project Information page

This page additionally includes *Hazard Magnitude* (H, I) and *Risk Preference* (J). These values are not used for any calculations in this version of EDGeS, and so are optional (they are placeholders). You may leave them blank or insert values. The example provided gives a hazard magnitude of 6.25 % with no associated uncertainty and a risk preference of neutral.

When you are ready to move on, click *Next* >>.

The program will prompt you to choose a name for your file. Ensure that you are in your desired save location. It is recommended that you keep all input files in one location, separate from any exported files. It is a good practice to keep your input files in their own folder. Enter ‘Riverbend Example’ as the file name and click *Save*. The file will be saved as a .csv file.

You will then be directed to the *Costs* page.

A.2. Entering Costs

To fill out the *Costs* Page, first calculate and gather the necessary information, as summarized in Table A.2 and Table A.3.

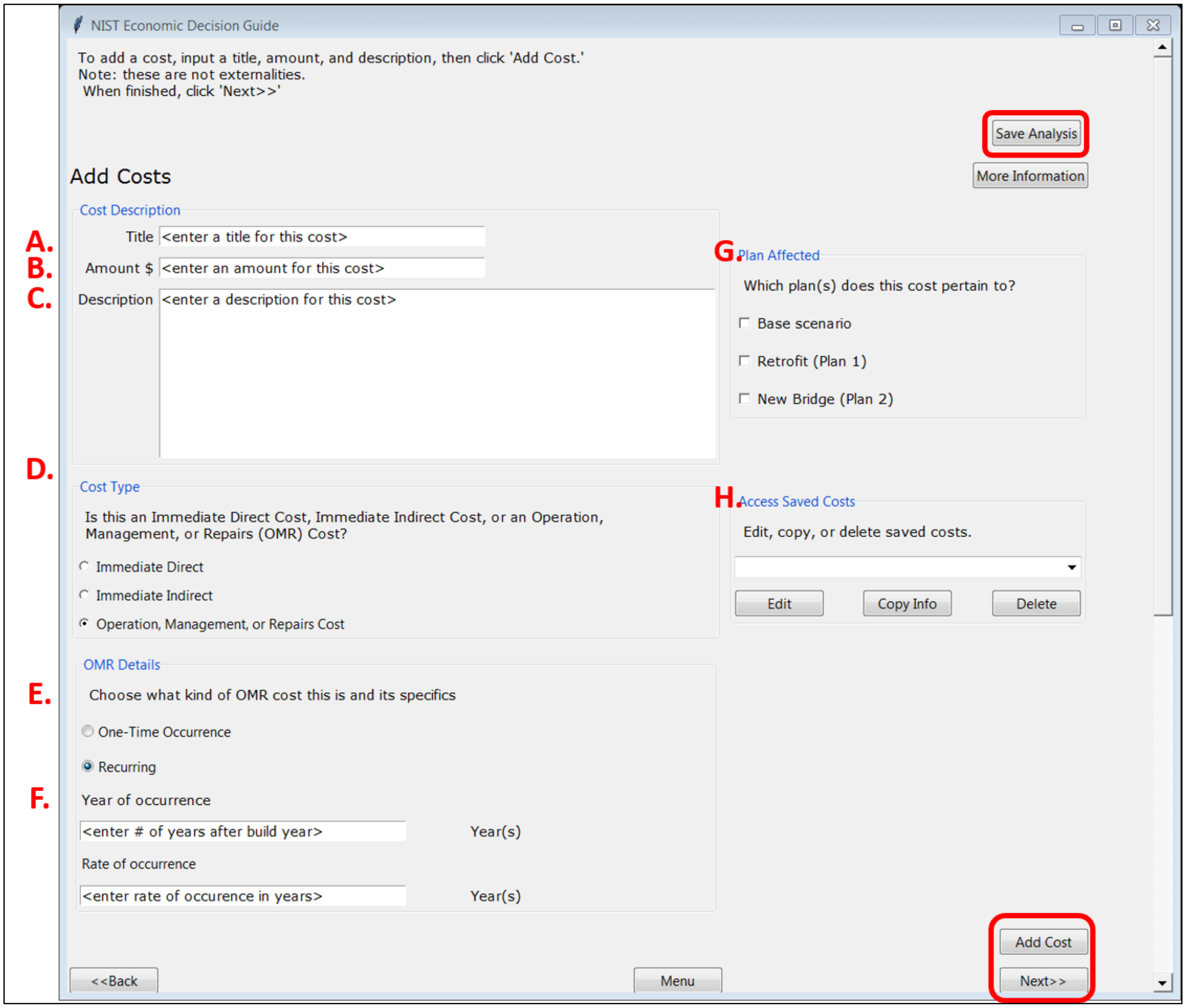


Figure A.3 The *Costs* page

For what follows, every field is referred to by name followed by the letter reference from Figure A.3.

Table A.2 Cost information associated with the Retrofit plan

Cost Title	Cost Type	Cost amount (USD)	Description
Retrofit Indirect Cost	Indirect	500 000	Indirect costs for retrofitting the old bridge. This includes the indirect costs of the retrofit actions as well as costs associated with diverted traffic.
Retrofit Direct Cost	Direct	3 000 000	Cost to retrofit the old bridge.

There are two costs associated with the Retrofit Plan. Start by entering information about the Retrofit Indirect Cost.

In the *Title* field (A), input the cost title where it says ‘<enter a title for this cost>.’ In the *Amount* field (B), input the cost amount where it says ‘<enter an amount for this cost>.’ In the *Description* field (C), input the cost description where it says ‘<enter a description for this cost>.’ In the *Cost Type* component (D), select the ‘Immediate Indirect’ radio button. In the plan affected component (G), select ‘Retrofit (Plan 1).’ Click *Add Cost*.

Now enter the information about the Retrofit Direct Cost.

In the *Title* field (A), input the cost title where it says ‘<enter a title for this cost>.’ In the *Amount* field (B), input the cost amount where it says ‘<enter an amount for this cost>.’ In the *Description* field (C), input the cost description where it says ‘<enter a description for this cost>.’ In the *Cost Type* component (D), select the ‘Immediate Direct’ radio button. In the plan affected component (G), select ‘Retrofit (Plan 1).’ Click *Add Cost*.

Table A.3 Cost information associated with New Bridge plan

Cost Title	Cost Type	OMR details	Cost amount (USD)	Description
New Bridge OMR	OMR	Starting the 1st year and every 1 year after	25 000	Cost of operating and maintaining new bridge. Includes costs of inspection as well as maintenance and deck and superstructure repair.
Additional Roadwork Indirect Cost	Indirect		120 000	Indirect costs to construct and update roadways to accommodate the new bridge.
Bridge Construction Indirect Cost	Indirect		175 000	Indirect costs associated with the construction of the new bridge including the costs of an environmental impact study.
Additional Roadwork Direct Cost	Direct		2 500 000	Cost to construct and update roadways to accommodate the new bridge.
Bridge Construction Direct Cost	Direct		4 250 000	Cost of new bridge including any right of way or land acquisition costs.
Additional Roadwork OMR	OMR	Starting the 1st year and every 1 year after	3710	Cost of operations and maintenance for upgraded and newly constructed roads to accommodate the new bridge.

There are six costs associated with the New Bridge Plan. Start by entering information about the New Bridge OMR Cost.

In the *Title* field (A), input the cost title where it says '<enter a title for this cost>.' In the *Amount* field (B), input the cost amount where it says '<enter an amount for this cost>.' In the *Description* field (C), input the cost description where it says '<enter a description for this cost>.' In the *Cost Type* component (D), select the OMR radio button. OMR details (E) will appear. Select 'Recurring.' The *Year of occurrence* and *Rate of occurrence* fields (F) will become available. Enter '1' in both fields. In the *Plan Affected* component (G), select 'New Bridge (Plan 2).' Click *Add Cost*.

Now enter information about the Additional Roadwork Indirect Cost.

In the *Title* field (A), input the cost title where it says '<enter a title for this cost>.' In the *Amount* field (B), input the cost amount where it says '<enter an amount for this cost>.' In the

Description field (C), input the cost description where it says '<enter a description for this cost>.' In the *Cost Type* component (D), select the 'Immediate Indirect' radio button. In the plan affected component (G), select 'New Bridge (Plan 2).' Click *Add Cost*.

Now enter information about the Additional Roadwork Direct Cost.

In the *Title* field (A), input the cost title where it says '<enter a title for this cost>.' In the *Amount* field (B), input the cost amount where it says '<enter an amount for this cost>.' In the *Description* field (C), input the cost description where it says '<enter a description for this cost>.' In the *Cost Type* component (D), select the 'Immediate Direct' radio button. In the plan affected component (G), select 'New Bridge (Plan 2).' Click *Add Cost*.

Now enter information about the Bridge Construction Direct Cost.

In the *Title* field (A), input the cost title where it says '<enter a title for this cost>.' In the *Amount* field (B), input the cost amount where it says '<enter an amount for this cost>.' In the *Description* field (C), input the cost description where it says '<enter a description for this cost>.' In the *Cost Type* component (D), select the 'Immediate Direct' radio button. In the plan affected component (G), select 'New Bridge (Plan 2).' Click *Add Cost*.

Now enter information about the Additional Roadwork OMR Cost. This OMR Cost is relatively similar to the 'New Bridge OMR Cost,' so instead of inputting it from scratch, begin by locating the 'New Bridge OMR Cost' from the *Access Saved Costs* dropdown menu (H) and select *Copy Info*. Notice that the fields from the *New Bridge OMR* cost have all been copied except for the *Plan Affected* component (G).

In the *Title* field (A), replace the cost title with 'Additional Roadwork OMR Cost.' In the *Amount* field (B), replace the cost amount. In the *Description* field, replace the cost description (C). The *Cost Type* component and OMR details may be left alone. In the *Plan Affected* component (G), select 'New Bridge (Plan 2).' Click *Add Cost*.

Now choose a cost from the *Access Saved Costs* dropdown menu (H), it doesn't matter which, and click *Edit*. Notice that all the fields are now re-populated with the appropriate information. Select *Cancel Edit*.

Select another cost from the *Access Saved Costs* dropdown menu (H), it does not matter which, and click *Delete*. Notice that there is a confirmation pop-up that contains the title, plan, amount, and description of the selected cost. Click *Cancel* to cancel the delete action.

Click *Save Analysis*. It is good practice to save each project regularly. The program will prompt you to choose a name for your file. Enter 'Riverbend Example' as the file name and click *Save*. The program will require validation to write over the 'Riverbend Example' created previously. Select *Yes*.

Click *Next >>*, you will be taken to the *Costs Uncertainties* page.

The *Costs Uncertainties* page will take some time to load.

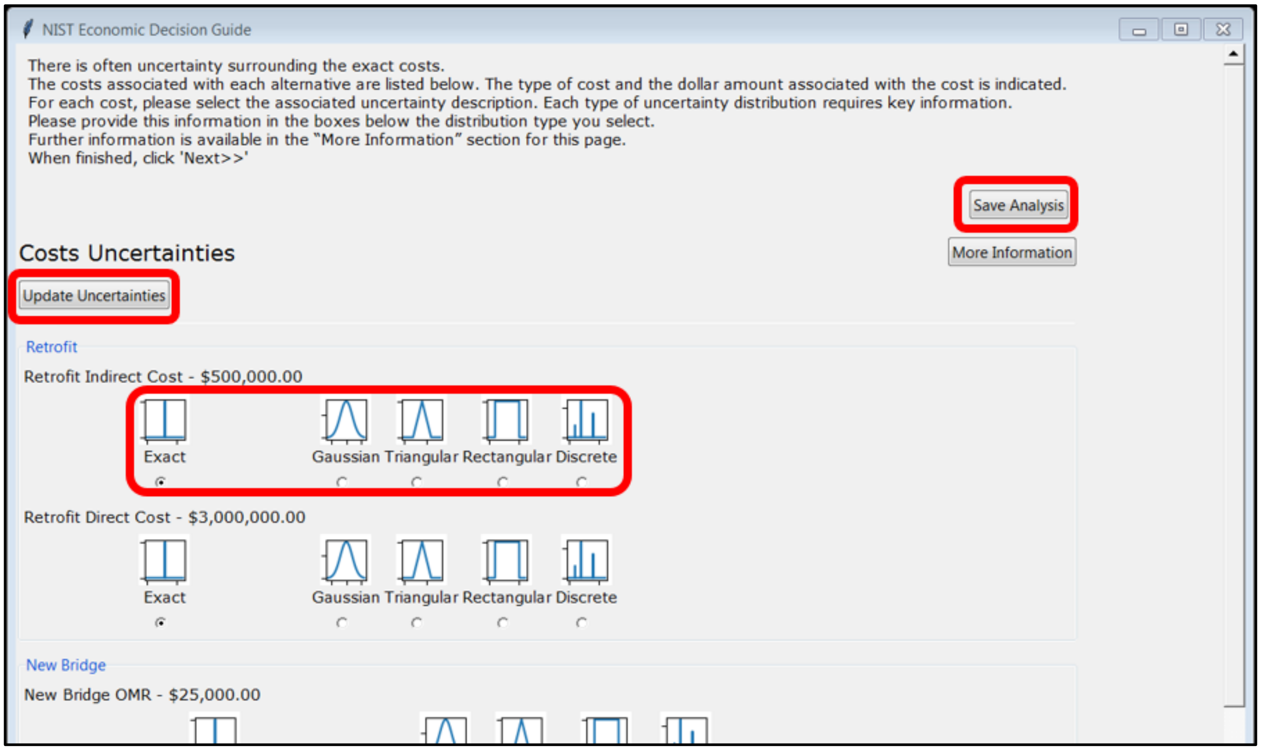


Figure A.4 Top of *Costs Uncertainties* page

As seen in Figure A.4, notice that all the costs entered on the previous page are listed by title and amount (USD). This list is automatically sorted and presented by plan. Each cost begins with the default uncertainty of *Exact*, which indicates no uncertainty around the point estimate value. First, gather the necessary information, as shown in Table A.4.

Table A.4 Uncertainties associated with costs

Cost	Distribution Type	Lower Bound (USD)	Upper Bound (USD)
Retrofit Indirect Cost	Triangular	475 000	750 000
Retrofit Direct Cost	Triangular	2 850 000	3 840 000
New Bridge OMR	Rectangular	21 375	30 000
Additional Roadwork Indirect Cost	Triangular	114 000	144 000
Bridge Construction Indirect Cost	Triangular	166 250	224 000
Additional Roadwork Direct Cost	Triangular	2 375 000	3 000 000
Bridge Construction Direct Cost	Triangular	4 037 500	5 440 000
Additional Roadwork OMR	Rectangular	3500	4250

Now, select the appropriate radio button for each listed cost given the uncertainty type. Then click *Update Uncertainties*. Notice that when you select a different uncertainty type, the input fields do not automatically change to match the new uncertainty. Clicking *Update Uncertainties* is required to update the input fields.

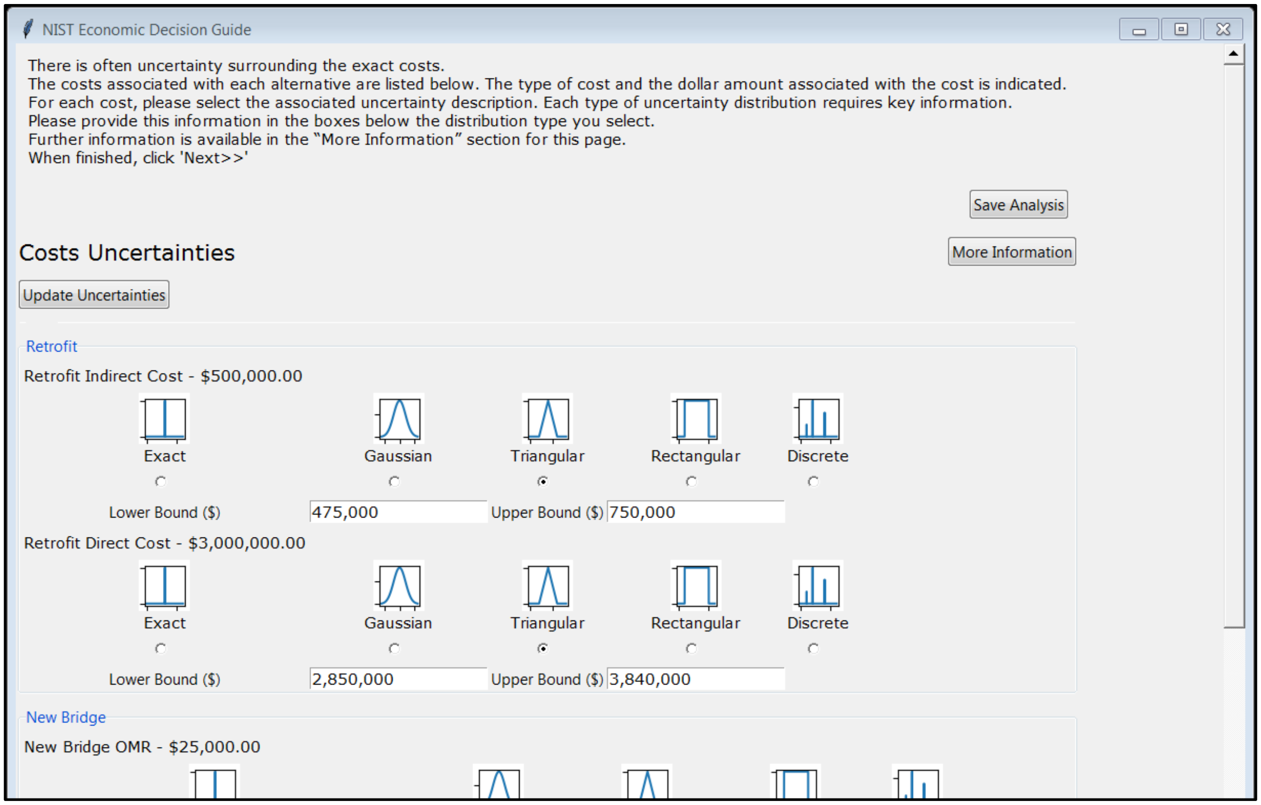


Figure A.5 Top of filled in *Costs Uncertainties* page

Now input the bounds associated with each cost by putting the lower bound in the field immediately to the right of *Lower Bound ($)* and putting the upper bound in the field immediately to the right of *Upper Bound ($)*. Your *Cost Uncertainties* page should look like Figure A.5.

Click *Save Analysis*. It is good practice to save each project regularly. The program will prompt you to choose a name for your file. Enter 'Riverbend Example' as the file name and click *Save*. The program will require validation to write over the 'Riverbend Example' created previously. Select *Yes*.

Click *Next >>* and you will be taken to the *Externalities* page.

A.3. Entering Externalities

To fill out the *Externalities* page (Figure A.6), first gather the necessary information as summarized in Table A.5. The Retrofit plan has no associated externalities.

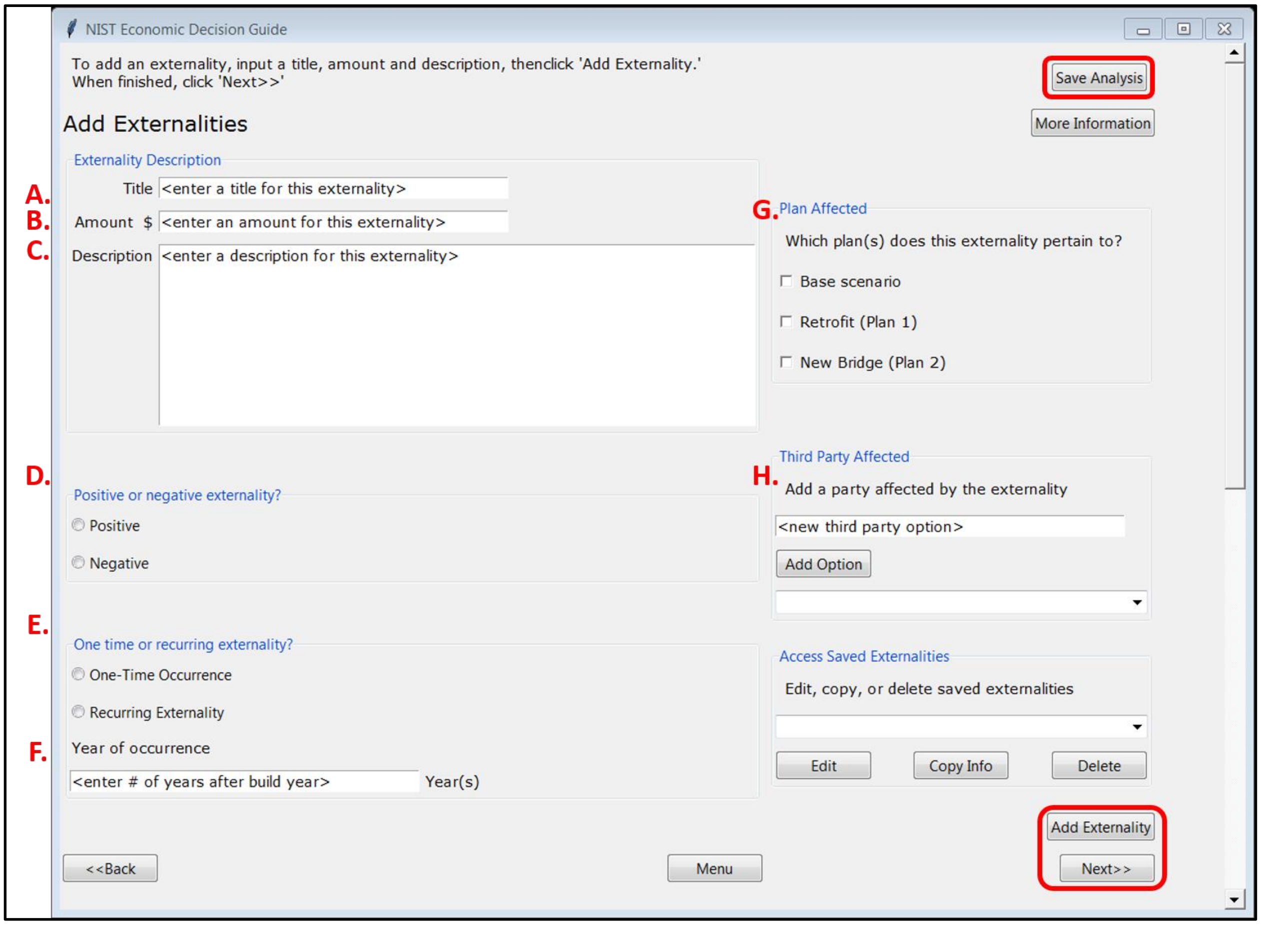


Figure A.6 The *Externalities* page

For what follows, every field is referred to by name followed by the letter reference from Table A.5. Three externalities are associated with the New Bridge plan. Start by entering information about the Greenhouse Gas Emissions.

Table A.5 The externalities associated with the New Bridge plan

Externality Title	Third Party Affected	Externality Type	Recurrence Information	Externality amount (USD)	Description
Greenhouse Gas Emissions	Community	Recurring	Starting the 1st year and every 1 year after	77 329	The reduction in greenhouse gas emissions incurred due to fewer vehicle-hours in traffic over the year. This assumes that traffic remains at pre-action levels (i.e., a more efficient road network won't attract more motorists).
Water Pollution	Community	Recurring	Starting the 1st year and every 1 year after	39 081	The reduction in water pollution incurred due to fewer vehicle-hours in traffic over the year. This assumes that traffic remains at pre-action levels (i.e., a more efficient road network won't attract more motorists).
Better linking of communities	Community	Recurring	Starting the 1st year and every 1 year after	39 799	More efficient traffic flow and the inclusion of a pedestrian crossing help strengthen the link between communities on the two sides of the river.

In the *Title* field (A), input the externality title where it says '<enter a title for this externality>.' In the *Amount* field (B), input the externality amount where it says '<enter an amount for this externality>.' In the *Description* field (C), input the externality description where it says '<enter a description for this externality>.' In the *Positive or negative* component (D), select the *Positive* radio button. In the *Recurrence* component (E), selecting the 'Recurring Externality' radio button. The Y*ear of occurrence* and *Rate of occurrence* fields (F) will become available. Enter '1' in both fields. In the *Plan Affected* component (G), select 'New Bridge (Plan 2).' In the *Third Party Affected* component (H), use the dropdown menu to select *Community*. Click *Add Externality*.

Enter the information about the Water Pollution.

In the *Title* field (A), input the externality title where it says '<enter a title for this externality>.' In the *Amount* field (B), input the externality amount where it says '<enter an amount for this externality>.' In the *Description* field (C), input the externality description where it says '<enter a description for this externality>.' In the *Positive or negative* component (D), select the *Positive* radio button. In the *Recurrence* component (E), selecting the 'Recurring Externality' radio button. The *Year of occurrence* and *Rate of occurrence* fields (F) will become available. Enter '1' in both fields. In the *Plan Affected* component (G), select 'New Bridge (Plan 2).' In the *Third*

Party Affected component (H), use the dropdown menu to select *Community*. Click *Add Externality*.

Now enter the information about the Better Linking of Communities.

In the *Title* field (A), input the externality title where it says '<enter a title for this externality>.' In the *Amount* field (B), input the externality amount where it says '<enter an amount for this externality>.' In the *Description* field (C), input the externality description where it says '<enter a description for this externality>.' In the *Positive or negative* component (D), select the *Positive* radio button. In the *Recurrence* component (E), selecting the 'Recurring Externality' radio button. The *Year of occurrence* and *Rate of occurrence* fields (F) will become available. Enter '1' in both fields. In the *Plan Affected* component (G), select 'New Bridge (Plan 2).' In the *Third Party Affected* component (H), use the dropdown menu to select *Community*. Click *Add Externality*.

Before leaving the *Externalities* page, in the *Third Party Affected* component (H), type a third party affected where it says '<new third party option>.' Since it will not be used, any party will work. Now click *Add Option*. Notice that your new third party is at the bottom of the dropdown menu. This can be applied to any externality, and if applied to an externality will be saved for this project.

Click *Save Analysis*. It is good practice to save each project regularly. The program will prompt you to choose a name for your file. Enter 'Riverbend Example' as the file name and click *Save*. The program will require validation to write over the 'Riverbend Example' created previously. Select *Yes*.

Click *Next >>* and you will be taken to the *Externalities Uncertainties* page.

The *Externalities Uncertainties* page will take some time to load.

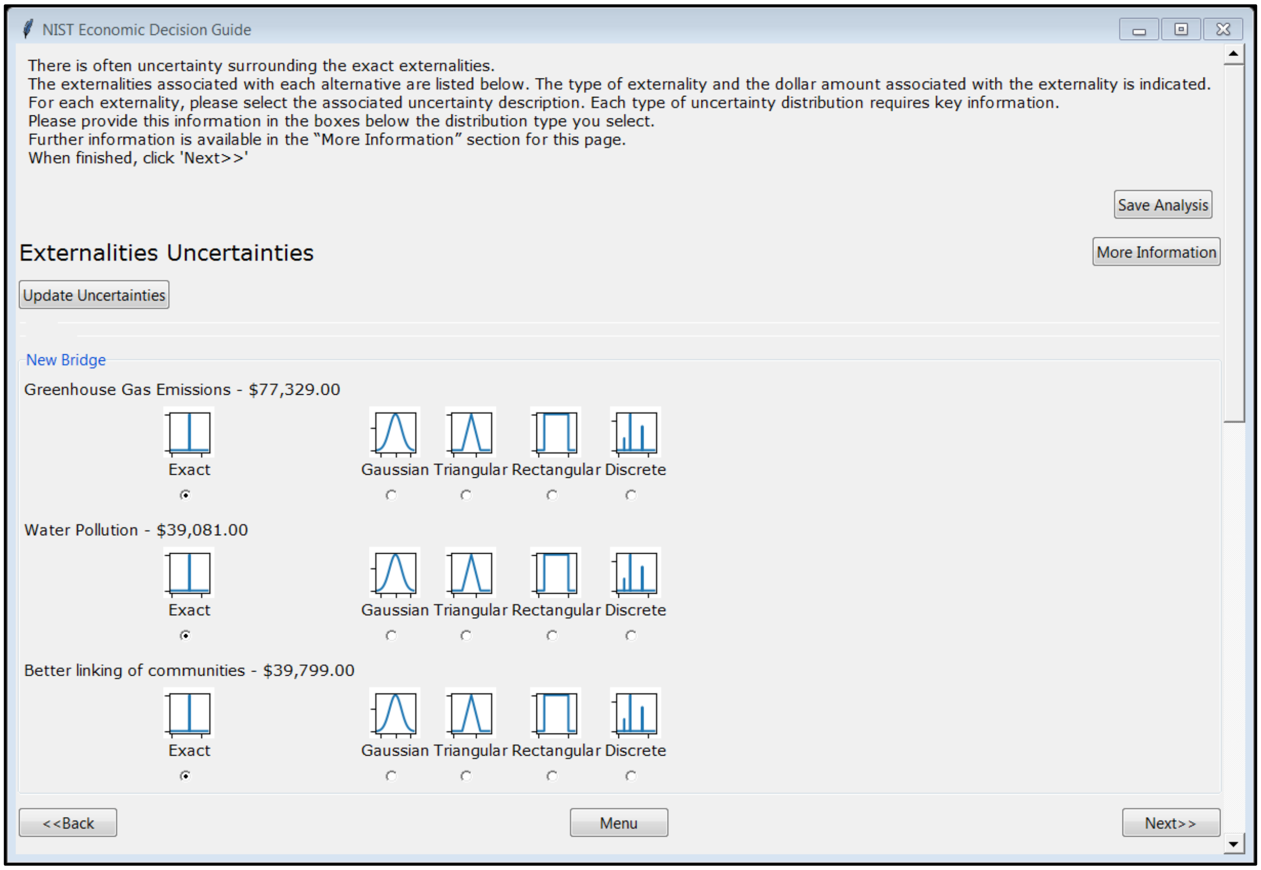


Figure A.7 The *Externalities Uncertainties* page

As seen in Figure A.7, notice that all the externalities entered on the previous page are listed by title and amount. This list is automatically sorted by plan. Each externality begins with default uncertainty of *Exact*, or no uncertainty around the point estimate value. First, gather the necessary information, as done in Table A.6.

Table A.6 Uncertainties associated with externalities

Externality	Distribution Type	More Information
Greenhouse Gas Emissions	Exact	
Water Pollution	Exact	
Better linking of communities	Exact	

Since every uncertainty here is the default, click *Next>>*. You will be taken to the *Benefits* page.

A.4. Entering Benefits

To fill out the *Benefits* page, first, gather the necessary information as summarized in Table A.7 and Table A.8.

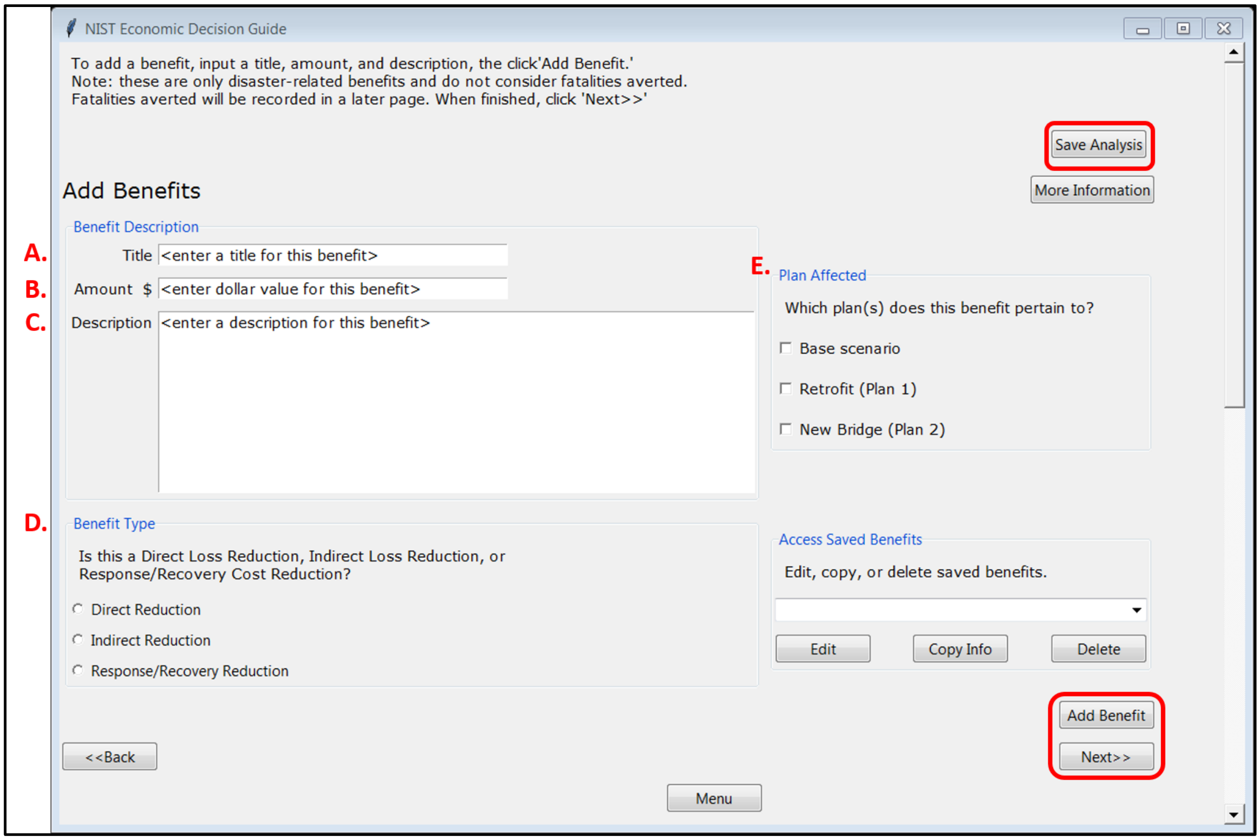


Figure A.8 The *Benefits* page

For what follows, every field is referred to by name followed by the letter reference from Figure A.3.

Table A.7 Benefits associated with the Retrofit plan

Benefit Title	Benefit Type	Benefit amount (USD)	Description
Retrofit Indirect Loss Reduction	Indirect	500 000	Estimated reduction in indirect losses as a result of a seismic event with a 25-year return period.
Retrofit Response and Recovery	Response and Recovery	600 000	Estimated reduction in response in recovery costs for a seismic event with a 25-year return period.
Retrofit Direct Loss Reduction	Direct	260 000	Estimated reduction in direct losses as a result of a seismic event with a 25-year return period.

The Retrofit plan has three associated benefits. Start by entering information about the Retrofit Indirect Loss Reduction benefit.

In the *Title* field (A), input the benefit title where it says ‘<enter a title for this benefit>.’ In the *Amount* field (B), input the benefit amount where it says ‘<enter an amount for this benefit>.’ In the *Description* field (C), input the benefit description where it says ‘<enter a description for this benefit>.’ In the *Benefit Type* component (D), select the ‘Indirect Reduction’ radio button. In the *Plan Affected* component (E), select ‘Retrofit (Plan 1).’ Click *Add Benefit*.

Now enter information related to the Retrofit Response and Recovery benefit.

In the *Title* field (A), input the benefit title where it says ‘<enter a title for this benefit>.’ In the *Amount* field (B), input the benefit amount where it says ‘<enter an amount for this benefit>.’ In the *Description* field (C), input the benefit description where it says ‘<enter a description for this benefit>.’ In the *Benefit Type* component (D), select the ‘Response/Recovery Reduction’ radio button. In the *Plan Affected* component (E), select ‘Retrofit (Plan 1).’ Click *Add Benefit*.

Now enter information about the Retrofit Direct Loss Reduction benefit.

In the *Title* field (A), input the benefit title where it says ‘<enter a title for this benefit>.’ In the *Amount* field (B), input the benefit amount where it says ‘<enter an amount for this benefit>.’ In the *Description* field (C), input the benefit description where it says ‘<enter a description for this benefit>.’ In the *Benefit Type* component (D), select the ‘Direct Reduction’ radio button. In the *Plan Affected* component (E), select ‘Retrofit (Plan 1).’ Click *Add Benefit*.

Table A.8 Benefits associated with the New Bridge plan

Benefit Title	Benefit Type	Benefit amount (USD)	Description
New Bridge Indirect Loss Reduction	Indirect	3 500 000	Estimated reduction in indirect losses as a result of a seismic event with a 25-year return period.
New Bridge Response and Recover	Response and Recovery	1 000 000	Estimated reduction in response in recovery costs for a seismic event with a 25-year return period.

The New Bridge Plan has two associated benefits. Start by entering information about the New Bridge Indirect Loss Reduction.

In the *Title* field (A), input the benefit title where it says ‘<enter a title for this benefit>.’ In the *Amount* field (B), input the benefit amount where it says ‘<enter an amount for this benefit>.’ In the *Description* field (C), input the benefit description where it says ‘<enter a description for this benefit>.’ In the *Benefit Type* component (D), select the ‘Indirect Reduction’ radio button. In the *Plan Affected* component (E), select ‘New Bridge (Plan 2).’ Click *Add Benefit*.

Now enter the information about the New Bridge Response and Recovery.

In the *Title* field (A), input the benefit title where it says ‘<enter a title for this benefit>.’ In the *Amount* field (B), input the benefit amount where it says ‘<enter an amount for this benefit>.’ In the *Description* field (C), input the benefit description where it says ‘<enter a description for this

benefit>.' In the *Benefit Type* component (D), select the 'Response/Recovery Reduction' radio button. In the *Plan Affected* component (E), select 'New Bridge (Plan 2).' Click *Add Benefit*.

Click *Save Analysis*. It is good practice to save each project regularly. The program will prompt you to choose a name for your file. Enter 'Riverbend Example' as the file name and click *Save*. The program will require validation to write over the 'Riverbend Example' created previously. Select *Yes*.

Click *Next* >> and you will be brought to the *Benefits Uncertainties* page.

The *Benefits Uncertainties* page will take some time to load.

Notice that all the benefits entered on the previous page are listed out by title and amount. This list is automatically sorted by plan. Each benefit begins with the default uncertainty type *Exact*, or no uncertainty. First, gather the necessary information, as done in Table A.9.

Table A.9 Uncertainties associated with benefits

Benefit	**Distribution Type**	**Standard Deviation (USD)**
Retrofit Indirect Loss Reduction	Gaussian	600 000
Retrofit Response and Recovery	Gaussian	180 000
Retrofit Loss Reduction	No uncertainty	N/A
New Bridge Indirect Loss Reduction	Gaussian	1 050 000
New Bridge Response and Recovery	Gaussian	300 000

Now, select the appropriate radio button for each listed benefit given the uncertainty type. Then click *Update Uncertainties*. Notice that when you select a different uncertainty type, the input fields do not automatically change to match the new uncertainty. Clicking *Update Uncertainties* is required to update the input fields. Now input the standard deviations on each benefit in the field immediately to the right of *Standard Deviation ($)*. Your *Benefits Uncertainties* page should look like Figure A.9.

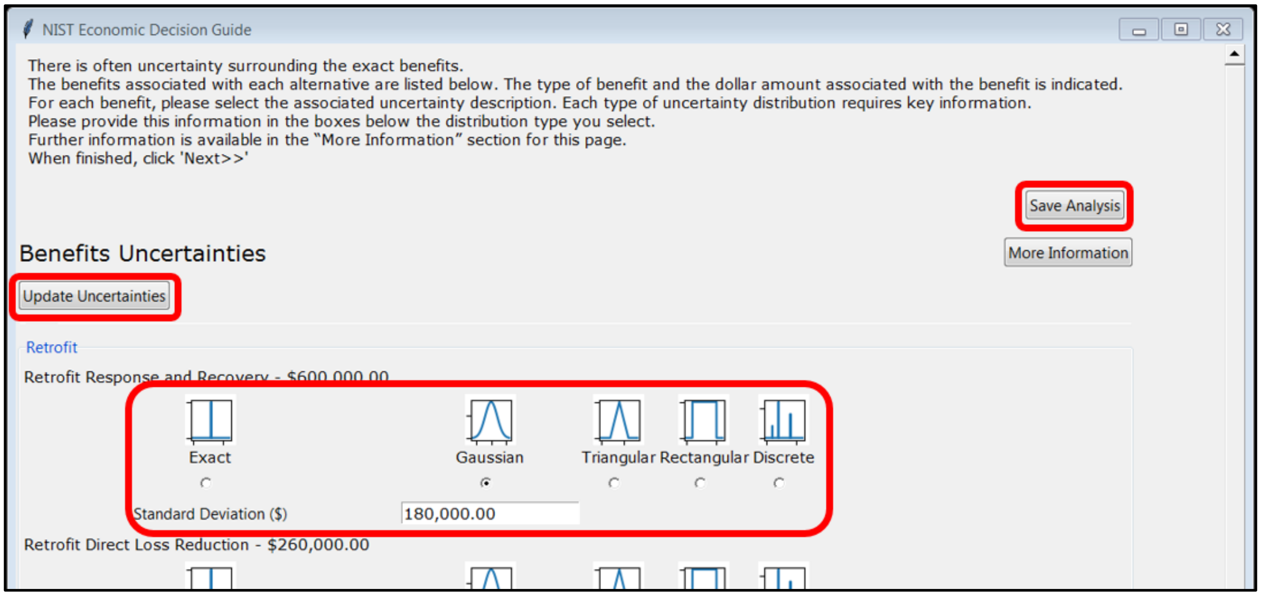


Figure A.9 Top of the *Benefits Uncertainties* page

Click *Save Analysis*. It is good practice to save each project regularly. The program will prompt you to choose a name for your file. Enter 'Riverbend Example' as the file name and click *Save*. The program will require validation to write over the 'Riverbend Example' created previously. Select *Yes*.

Click *Next>>* and you will be taken to the *Fatalities Averted* page.

A.5. Entering Fatalities Averted

To fill out the *Fatalities Averted* page, first, gather the necessary information as done in Table A.10. For what follows, every field is referred to by name followed by the letter reference from Figure A.10.

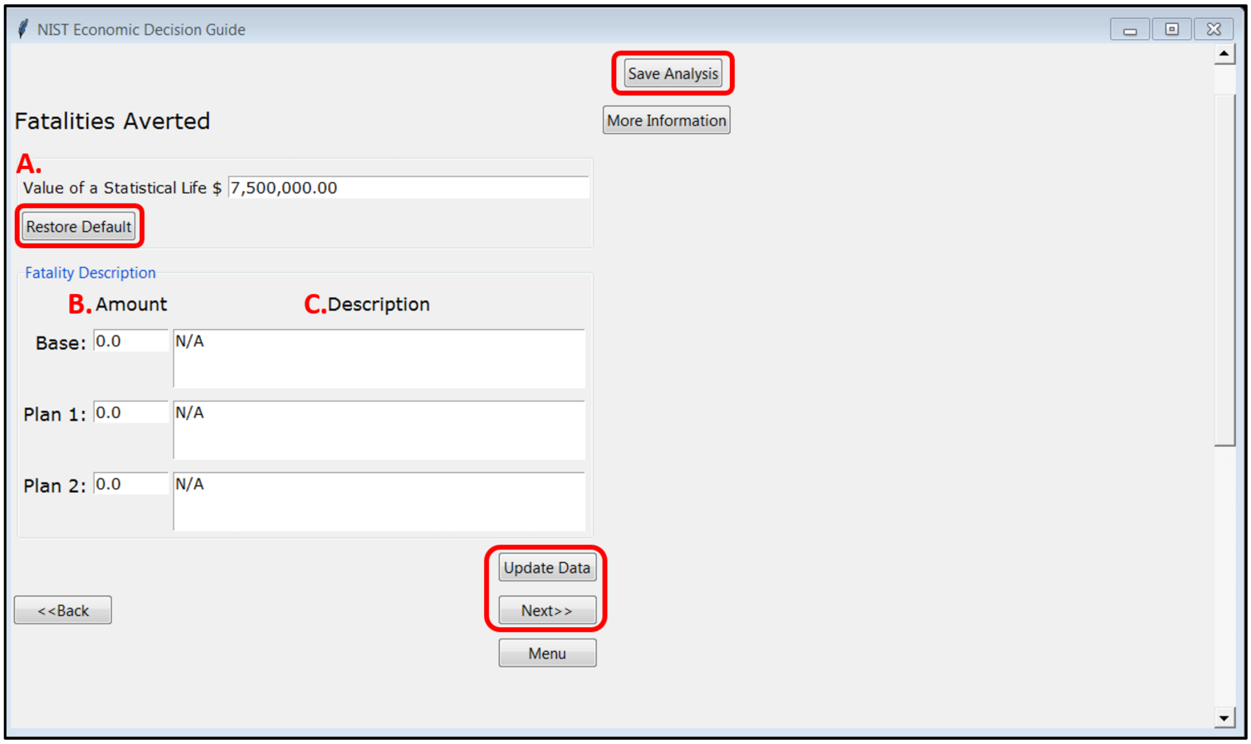


Figure A.10 The *Fatalities Averted* page

Here, the assumed value of a statistical life is the default value of 7 500 000 USD. Change the value in the field next to *Value of a Statistical Life* (A), and then click *Restore Default*.

Table A.10 Fatalities averted associated with all plans

Plan	**Amount (Lives saved)**	**Description**
Base	0.0	
Retrofit (Plan 1)	0.1	Estimated reduction in the number of fatalities due to a seismic event with a 25-year return period.
New Bridge (Plan 2)	0.2	Estimated reduction in the number of fatalities due to a seismic event with a 25-year return period.

In the *Amount* column (B) for the respective plan, input the appropriate number of fatalities averted. In the *Description* column (C) for the respective plan, input the appropriate description. Click *Update Data*.

Click *Save Analysis*. It is good practice to save each project regularly. The program will prompt you to choose a name for your file. Enter ‘Riverbend Example’ as the file name and click *Save*. The program will require validation to write over the ‘Riverbend Example’ created previously. Select *Yes*.

Click *Next>>* and you will be brought to the *Non-Disaster Related Benefits* page. You will get a pop-up saying, “Fatality Aversion Statistics has been successfully updated.” Any time you move on from a page, EDGeS will validate and save any data on the page to avoid losing your work.

A.6. Entering Non-Disaster Related Benefits

To fill out the Non-Disaster Related Benefits page, first, gather the necessary information, as summarized in Table A.11. The Retrofit plan has no non-disaster related benefits. For what follows, every field is referred to by name followed by the letter reference from Figure A.11.

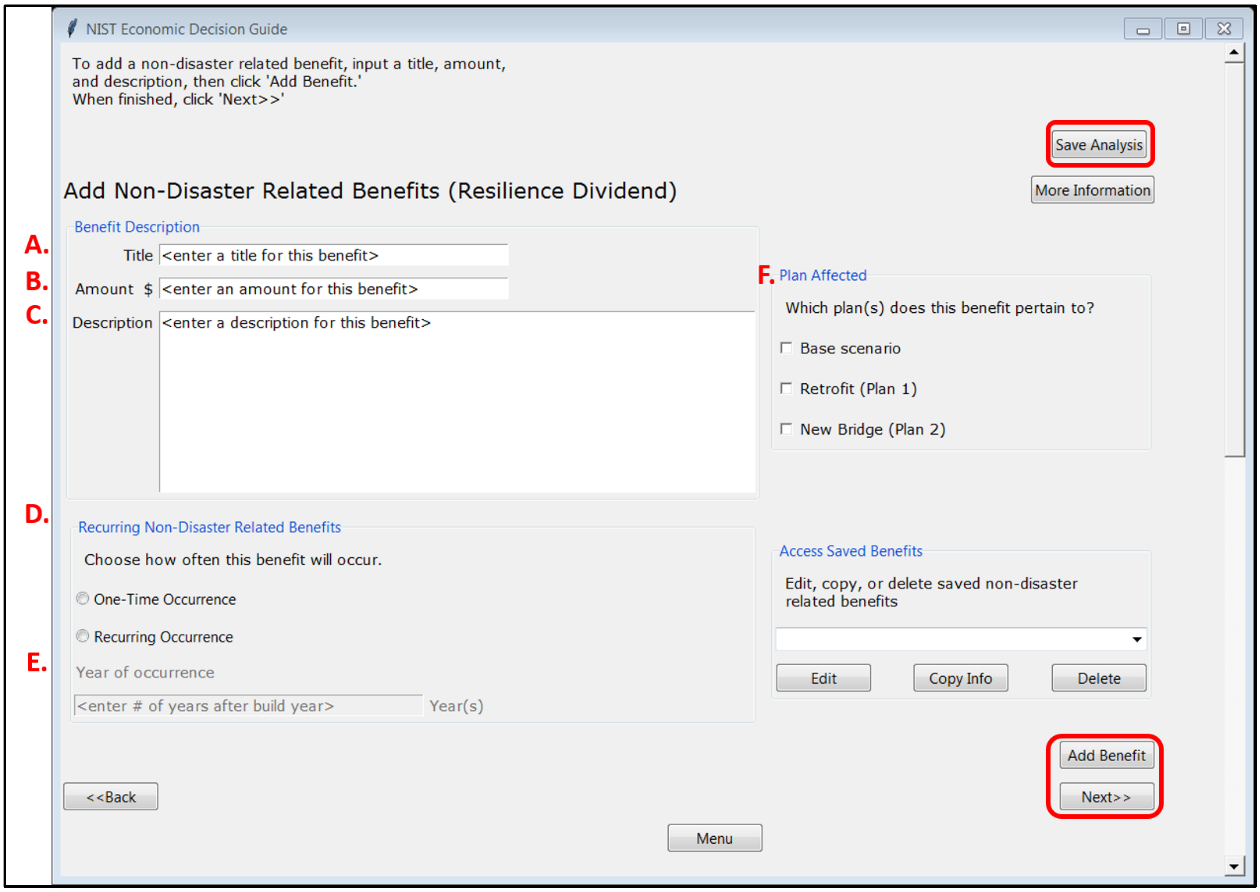


Figure A.11 The *Non-Disaster Related Benefits* page

Table A.11 Non-Disaster Related Benefits associated with the New Bridge plan

Benefit Title	Benefit Type	Recurrence Information	Benefit amount (USD)	Description
Reduced Commute Time	Recurring	Starting the 1st year and every 1 year after	100 000	Estimated benefit incurred due to the reduction of vehicle-hours in traffic as a result of an additional crossing. This benefit is separate from the externalities that focus on community-level environmental and social impacts, which are not internalized. Instead represent the value of a reduction in travel time itself internalized into the design process.

The New Bridge Plan has one Non-Disaster Related Benefit. Enter the information related to the Reduced Commute Time.

In the *Title* field (A), input the benefit title where it says '<enter a title for this benefit>.' In the *Amount* field (B), input the benefit amount where it says '<enter an amount for this benefit>.' In the *Description* field (C), input the benefit description where it says '<enter a description for this benefit>.' In the *Recurrence* component (D), select the 'Recurring' radio button. The *Year of occurrence* and *Rate of occurrence* fields (E) will become available. Enter '1' in both fields. In the *Plan Affected* component (F), select 'New Bridge (Plan 2).'

Click *Save Analysis*. It is good practice to save each project regularly. The program will prompt you to choose a name for your file. Enter 'Riverbend Example' as the file name and click *Save*. The program will require validation to write over the 'Riverbend Example' created previously. Select *Yes*.

Click *Next >>* and you will be brought to the *Non-Disaster Related Benefits Uncertainties* page.

The *Non-Disaster Related Benefits Uncertainties* page will take some time to load. Notice that the benefit saved on the previous page is listed out by title and amount, sorted by plan, each with the default of no uncertainty. First, gather the necessary information, as done in Table A.12.

Table A.12 Non-Disaster Related Benefits associated with the New Bridge plan

Benefit	Distribution Type	Lower Bound (USD)	Upper Bound (USD)
Reduced Commute Time	Triangular	70 000	115 000

Now, select the 'Triangular' radio button. Then click *Update Uncertainties*. Notice that when you select a different uncertainty type, the input fields do not automatically change to match the new uncertainty. Clicking *Update Uncertainties* is required to update the input fields. Now input the bounds associated with this benefit by putting the lower bound in the field immediately to the right of *Lower Bound ($)* and putting the upper bound in the field immediately to the right of *Upper Bound ($)*. When done, your *Benefits Uncertainties* page should look like Figure A.12.

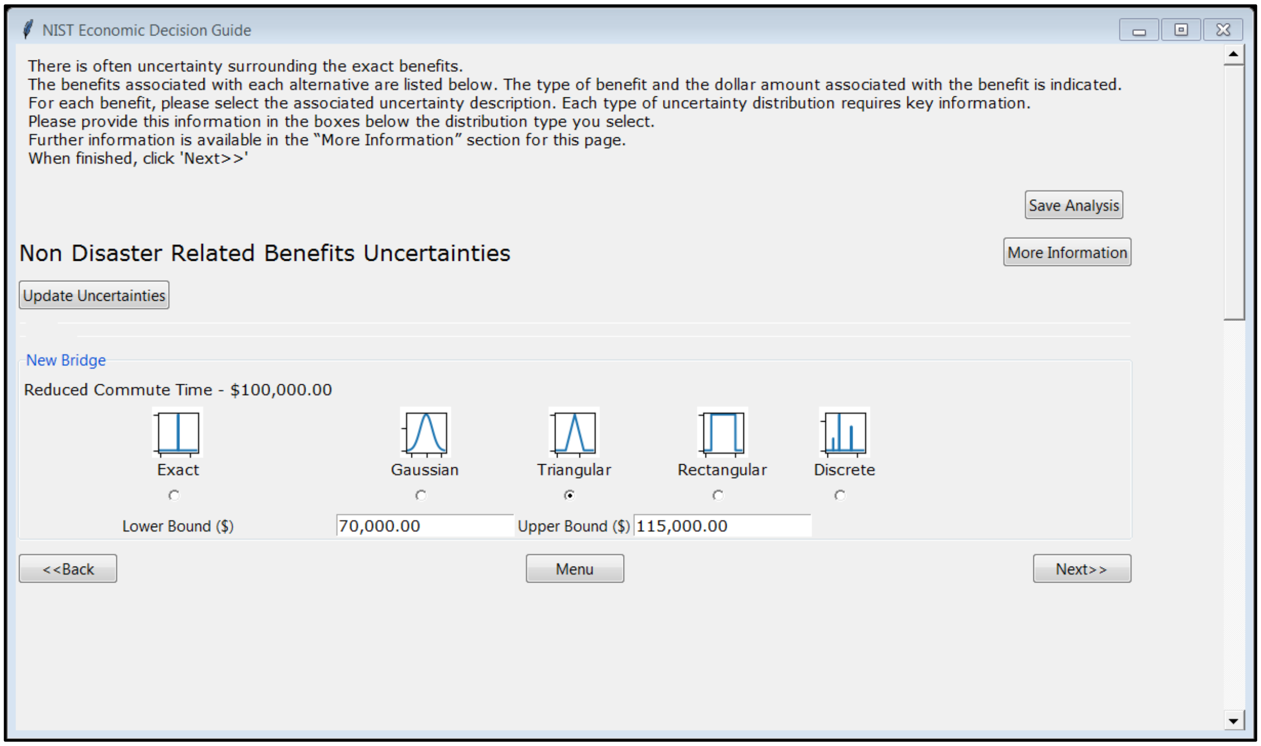


Figure A.12 The *Non-Disaster Related Benefits Uncertainties* page

Click *Save Analysis*. It is good practice to save each project regularly. The program will prompt you to choose a name for your file. Enter 'Riverbend Example' as the file name and click *Save*. The program will require validation to write over the 'Riverbend Example' created previously. Select *Yes*.

Click *Next >>* and you will be brought to the *Analysis Information* page.

A.7. Run, view, and export results

From the *Analysis Information* page, seen in Figure A.13, it is possible to run the analysis both with and without uncertainty.

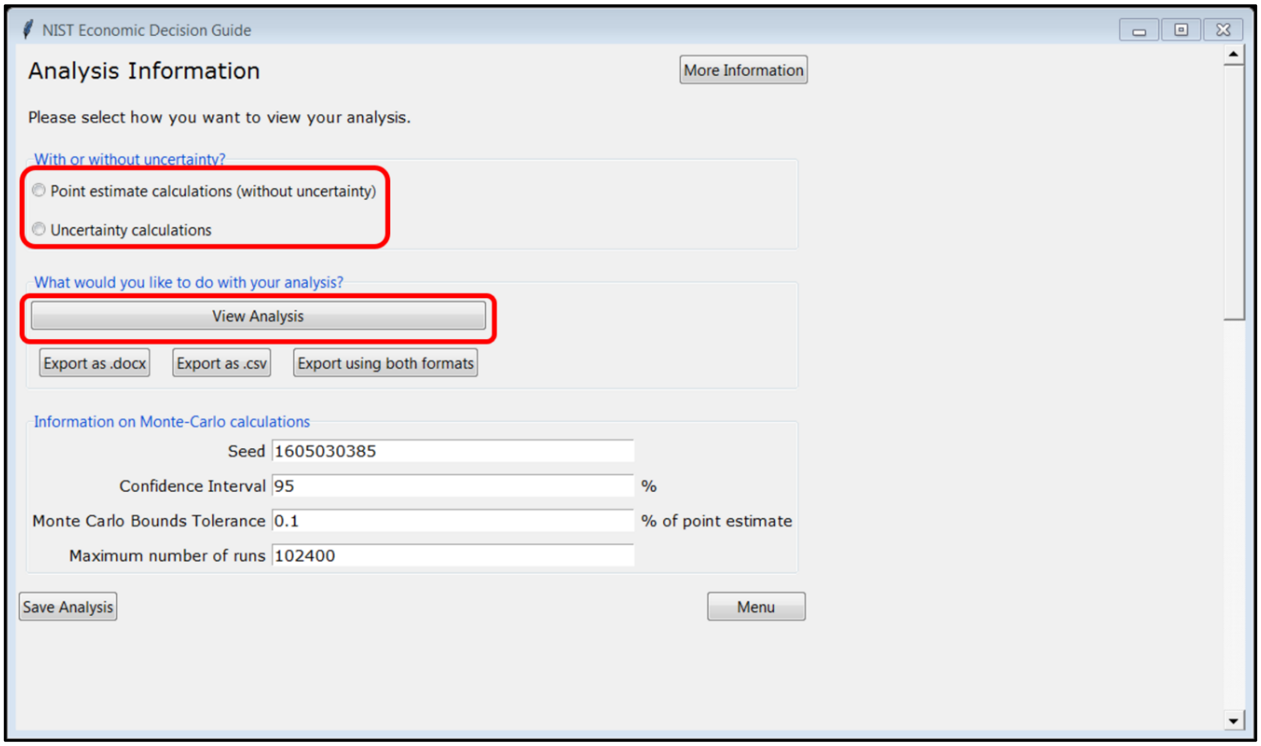


Figure A.13 The *Analysis Information* page

To run and export this analysis without the uncertainty aspects, select the 'Point estimate calculations (without uncertainty)' radio button and click *View Analysis*. A new window will come up with all the analysis results. To export the summary, click *Export Summary* at the bottom of the page and on the new *Export* window seen in Figure A.14, select *Both formats*. First, it will save the Word export. The program will prompt you to choose a name for your file. Navigate to your folder for export files, and save the file as 'Riverbend Word export.' Now it will save the .csv file. The program will prompt you to choose a name for your file. Navigate to your folder for export files, and save the file as 'Riverbend csv export.'

Figure A.14 File export choice dialog box

To run and export this analysis with the uncertainty aspects included in the calculations, select the 'Uncertainty calculations' radio button. Beneath the buttons is the information on Monte-Carlo component. Notice that these values are filled in with defaults, and so do not need to be set or changed. Click *View Analysis*. A new window will appear, with the sentence 'The Monte-Carlo simulations will take some time to run. Please be patient while they compute.' Do not close this window. When the calculations are complete, this window will close itself, and a new window will pop-up with all the analysis results.

To export the summary, click *Export Summary* and on the new *Export* window, select *Both formats* as the answer to what format to use for the export. First, it will save the Word export. The program will prompt you to choose a name for your file. Navigate to your folder for export files, and save the file as 'Riverbend Word uncertainties export.' Now it will save the .csv file. The program will prompt you to choose a name for your file. Navigate to your folder for export files, and save the file as 'Riverbend csv uncertainties export.'

Appendix B. Example Scenarios

In addition to the *Riverbend* example, three other case study illustrations are available for EDGeS (These are fictitious examples.) The narratives of these case studies are presented in brief in Section 3.1. Each is presented with a narrative, EDGeS input, and results interpretation here. These case studies are as follows:

1. The *Hospital* case study—Appendix B.1
2. The *Buyout/Levee* case study—Appendix B.2
3. The *WUI* case study—Appendix B.3

Each case study attempts to extend the use of EDGeS beyond its current functionality in ways that a practitioner may find useful. Red values in parentheses indicate a negative dollar value for all tables in this Appendix.

B.1. *Hospital* Case Study

The purpose of the *Hospital* case study is to illustrate how to incorporate certain timing aspects of cash flows that are not currently built into EDGeS into an analysis. This method requires an additional calculation to apply a modification to benefits. It should be noted that, while EDGeS does allow for accurate modifications when including timing for the point estimate analysis, EDGeS has limitations with these modifications under uncertainty. Furthermore, the intermediate output is not currently designed to account for such modifications. A discussion of this is presented later in the Appendix.

Narrative

A medium-sized city situated near the mouth of a river recently experienced a 50-year flood. During the flood, their hospital, located in the 50-year flood plain but outside of the 25-year flood plain, flooded, requiring an evacuation of all patients and rendering it inoperable for a full year after the event (Cabbagestalk 2016). Lacking a viable hospital, all hospital traffic was required to visit nearby hospitals in other towns (assumed to have sufficient capacity for the additional patients). This meant that an average of 20 km was added to any hospital related trips from the city. A full analysis of the hospital after the disaster yielded the results in Table B.1.

Recognizing the hardship caused by the loss of the hospital, the city decided to relocate the hospital to an area outside of the 50-year flood plain. Apart from increasing their resilience related to flooding events, the hospitals will be designed to current standards of hospital construction. While not necessarily state of the art, the new facility will be an upgrade to their original hospital, which was half a century old. The key decisions related to the hospital is where it will be sited. The city has determined two potential locations: 1. Construct a hospital with 3207 m^2 of floor space on 56 656 m^2 in a suburban area of the city, or 2. construct a hospital with 3601 m^2 of floor space on 32 375 m^2 in the city center.

Table B.1 Estimated losses from instigating flood

Item	Loss classification	Value
Statistical lives lost (flood)	Human Life	11 people
Additional statistical lives lost (additional travel time)[25]	Human Life	40 people[26]
Structural damage	Direct	$32 million (Johannesen 2008, June 19)
Hospital income (full year)	Indirect	$276 million (Federal Emergency Management Agency 2008)
Diverting ambulances	Indirect	$1100 per trip[27] (McConnell et al. 2006)
Mold remediation	Response and Recovery	$24 million (Kisken 2007, Aug 22)
Evacuation cost	Response and Recovery	$75 000 (Zavadi 2013 July 9)

Assumptions

The following values are assumed for both alternatives:

Planning horizon – 100 years
Recurrence rate of Flood Event – 50 years
Real discount rate – 8 %
Value of a statistical life – 7 900 000 USD (Applebaum 2011, Feb. 16)
Value of a statistical infection - 13 577 USD [28]

Other key assumptions have been made to simplify the example. These are not necessarily realistic and should not be considered prescriptive for an actual LCC analysis.

1. The hospital is the only medical center effected. In practice, many hospital procedures are performed in smaller practices that may be owned by the hospital, but are not collocated with the hospital. Disruption to these services can be just as fatal depending on the service provided, dialysis for instance, but such disruptions are omitted here.
2. In conjunction with the first assumption, the impact to public transportation is negligible. The cost of medical services for severe disabilities, or the nature of a disability itself, may

[25] Lives lost in travel time are those that are a direct result of the longer time to reach the hospital over the year that the hospital is closed.
[26] Calculated assuming 2000 ambulance trips per year (U.S. Dept. of Health and Human Services 2015) over the additional 20 km per trip and an increased chance of mortality of 1 % per 10 km (Nicholl et al. 2007).
[27] 2000 trips assumed per year
[28] Value of statistical infection derived using the total cost of non-fatal nosocomial infections in the US for a year (9.8 billion USD) (Zimlichman et al. 2013) and dividing it by the number of non-fatal nosocomial infections per year (721 800) (Centers for Disease Control and Prevention 2016)

preclude personal travel to and from services. As with the first assumption, these considerations are omitted.

3. The effects of worker dislocation are omitted, and it is assumed that after recovering from the disaster the hospital returns to full staffing immediately.
4. Local and regional economic effects of moving the hospital are omitted.
5. The effects of floods of other magnitudes (e.g.,100-year, 25-year, 10-year, etc.) are irrelevant in the context of this analysis. In essence, lesser floods don't have the capacity to impact the hospital nor access to it at either location, while a greater flood (200-year or 500-year) is assumed to be so devastating that relocating the hospital would not have any meaningful impact on the outcome. Information on floodplains for intermediate floods (37-year flood for instance) are assumed to not exist. See the *Buyout/Levee* example in Appendix B.2 for an example where this assumption is invalid and the means to correct for it.
6. There is no dependence between any of the distributions used for the uncertainty analysis. EDGeS currently lacks the ability to consider dependencies.
7. The analysis compares all values relative to the implicit option of doing nothing.

Assumptions related to specific values derived for the analysis are mentioned as they arise from the narrative.

Cost Data

Estimates made on the basic features of a hospital located on each site based on the nature of the location, the available budget, and examinations of hospitals of similar size and purpose. Table B.2 outlines the estimated costs at each site.

The timeline for completion is one year for the design and bidding process, and another two for the construction and commissioning (including transfer) process (Haefner 2016, June 08). Once in operation it is expected to have a 100-year planning horizon. The old hospital, at this point back in operation, would remain in operation for the three years it takes for the new hospital to be completed, after which it will be decommissioned and sold. The decommissioning is expected to cost another three million USD and take a full year (Kulia 2013, June 5; New York City Health and Hospitals Corporation 2013, Nov. 7; Martin, Chip 2013, June 18).

Once decommissioned the old structure and the land surrounding it are expected to be sold. Based on land value and knowledge of previous sales the city expects the hospital, with land, to sell for around two million USD (Burns 2017, Jan 27; Dunn 2010, Nov. 24).

Table B.2 Costs associated with the two hospital site options

Cost classification	Item	Site 1 (Suburbs)	Site 2 (City Center)
Direct	Construction[29]	$2960.77/m^2	$3336.81/m^2
	Land acquisition	$3.71/m^2 (Morris and Polumbo 2007)	$8.67/m^2 [15] (Morris and Polumbo 2007)
	Outfitting[30]	$7045.53/m^2	$7045.53/m^2
	Transfer[31]	$28 million	$30 million
Indirect	Indirect (Including contractor overhead)[32]	30 % of direct costs	30 % of direct costs
Operations, Maintenance, and Repair	Operations	34.66/m^2 (OMBHCFC 2010)	34.66/m^2 (OMBHCFC 2010)
	Maintenance	140.79/m^2 (OMBHCFC 2010)	129.17/m^2 (OMBHCFC 2010)
	Utilities	43.70/m^2 (OMBHCFC 2010)	40.69/m^2 (OMBHCFC 2010)

Benefit Data

Event-Related Benefits (*Benefits* screen in EDGeS)

In selecting each potential site, the city examined the impact on expected losses in the event of another 50-year flood event. Based on the analysis the loss reductions in Table B.3 are expected.

If there is enough rain to induce flooding, it would be expected that some damage would occur to the hospital itself, but it would be limited to the basement. A similar argument is made for mold remediation. In the comparison, it's noted that Site 1's characteristics make it more susceptible to basement flooding, translating to more damage from heavy rains, and increased potential for lost revenue as any basement flooding is dealt with. No evacuation should be necessary for either hospital.

[29] Based on ranges of cost per square foot, converted to cost per square meter, from (Design Cost Data 2014; Garske 2012, Aug 19; Groves 2007, June 5; UCLA Health; Pope 1991)
[30] Cost per square meter obtained by normalizing numbers from (Blackford 2013, June 10)
[31] Cost per square meter obtained by normalizing values from (Garrick 2009, Apr. 13); Lou 2009, Mar. 9)
[32] Base rate of 24 % from Montgomery County Department OF Housing and Community Affairs (2016) with an additional 6 % added based in part on National Academy of Sciences (1968)

Table B.3 Reductions in flood related losses for each hospital site

Item	Loss classification	Site 1 Reduction	Site 2 Reduction
Statistical lives lost (flood)	Human Life	0 people	0 people
Statistical lives lost (additional travel time)	Human Life	40 people	40 people
Structural damage	Direct	$22.5 million	$27.5 million
Hospital income (full year)	Indirect	$250 million	$271 million
Diverting ambulances	Indirect	$1100 per trip	$1100 per trip
Mold remediation	Response and Recovery	$18 million	$19 million
Evacuation cost	Response and Recovery	$0.075 million	$0.075 million

Fatalities Averted

Most deaths due to flooding are a result of drowning. An operational hospital is not as vital to preventing drowning deaths as is evacuation, education, and the actions of first responders. Under this assumption, the new hospital would not prevent any deaths directly related to the flood. It's also assumed that all lives lost due to an increase in transport time to a functional hospital would be saved, as would the cost of diverting ambulances.

Non-Disaster Related Benefits (Resilience Dividend)

Apart from the flood related benefits, the city also notes that there are other positives that come from the new hospitals. Both would be built to higher standards than the old hospital, thus reducing the potential for medical errors and increasing efficiency. Given the larger amount of space in Site 1, the hospital could be better optimized for efficiency over the space, resulting in more gains than Site 2. Site 2 would have the potential to cut down on ambulance travel times as well, while they would be relatively unchanged with Site 1's location. All values are assumed yearly.

Table B.4 presents the potential non-flood related benefits. All values are assumed yearly.

Table B.4 Non-flood related benefits for each hospital site

Item	Site 1	Site 2
Statistical lives saved due to a decrease in medical errors	4	2
Decrease in nosocomial infections (non-fatal)	20	15
Decrease in average travel distance	0	1 km

Externalities

No externalities are assumed for this example. This is highly unrealistic, but externalities are unnecessary to achieve the purpose of this example. Omission of externalities also allows for a better display of the effects of the methodology described below.

EDGeS Inputs

Point Estimate/Baseline Analysis

The base values for cost inputs into EDGeS are presented in Table B.5. All costs are assumed as occurring in year zero, as that is when the city will set aside the funds. As such, even though the money is not actually spent, it is not available to the city for other purposes. This value is assumed to account for discounting in the three-year construction phase cash flows. OMR costs (excluding decommissioning) are annually recurring and start accruing after year three, once the hospital is completely constructed and has entered service.

Table B.5 Cost inputs values for EDGeS for each hospital site

Cost Category	Site 1	Site 2
Direct (Excluding Decommissioning)[33]	$60.30 million	$65.67 million
Indirect	$18.09 million	$19.7 million
Operations, Maintenance and Repair	$0.61 million per year	$0.57 million per year
Decommissioning (Treated as one-time OMR cost at year 3)	$2 million	$2 million

Table B.6 converts the values for *Additional statistical lives lost*, *diverting ambulances*, and *Statistical lives lost* from Table B.3 into input ready values. All other values in Table B.3 may be input directly. Non-disaster related benefits and externalities start accruing after the third year, after the hospital is completely constructed and has entered service.

Table B.6 Flood related loss reduction (*Benefits*) input for each hospital site

Item	Site 1 Reduction	Site 2 Reduction
Statistical lives lost (flood)	0	0
Statistical lives lost (additional travel time)[34]	40 people	40 people
Diverting ambulances[35]	$2.2 million	$2.2 million

[33] Decommissioning is not an immediate direct cost so it is handled as a separate OMR cost in the program.
[34] Input into Fatalities Averted page
[35] 2000 trips assumed per year

One issue that arises in inputting this information in EDGeS occurs when looking at the non-disaster benefits. These benefits don't accrue until the hospital is completed, however EDGeS automatically applies them for all years. In order to address this, their value needs to be removed from the analysis. This can be back ended into the program through the *Externalities* input. Doing so first requires calculating the annualized benefit of the on-disaster benefits using Eq. B-1.

$$B * \lambda = A \tag{B-1}$$

Where: B is the value of the on-disaster benefit, λ is the Poisson distribution parameter equal to $\frac{1}{Return\ Rate}$, and A is the annualized non-discounted on-disaster benefit.

These values can be entered into the *Externalities* as a negative one-time externality for years one, two, and three. This removes the on-disaster benefits for those years, but means the total *Externalities* output will now be incorrect while the final values *Present Values* will now be correct. Any economic indicators omitting externalities in the output will also be incorrect. By defining the owner of the *Externalities* as "Correction" in the input, it becomes possible to easily single them out in the input and output. These inputs are found in Table B.7. Similar modifications can be done to allow for the timing out of *Cost* cash flows, or terminating a recurring cost before the planning horizon is reached. Alternatively, the modifications could be added via the *Benefits* input page using negative values.

Table B.7 Modifications input for flood related benefits for years one through three for each hospital site.

Corrected Line Item[36]	Modification Value Site 1	Modification Value Site 2
Aggregated DRBs	$5.86 million	$6.40 million
Value of fatalities averted	$6.32 million	$6.32 million

Table B.8 summarizes the non-disaster related benefits. Non-disaster related benefits are annually recurring and accrue starting after year three, after the hospital is completely constructed and has entered service.

[36] Values input in the *Externalities* page in EDGeS

Table B.8 Non-disaster related benefits for each hospital site

Item	Site 1	Site 2
Statistical lives saved due to a decrease in medical errors (annual starting in year four)	$31.6 million	$15.8 million
Decrease in nosocomial infections (non-fatal) (annual starting in year four)	$0.272 million	$0.204 million
Decrease in average travel distance[37] (annual starting in year four)	$0	$2 million

Uncertainty Analysis

The costs under uncertainty are presented in Table B.9. Right skewed distributions are assumed for some costs due to a higher likelihood of cost overrun. Table B.10 includes the uncertainty input for on-event benefits. Values for *Min, Max,* and *St. Dev.* are assumed without justification.

Table B.9 Cost uncertainty inputs for each hospital site

Cost Category	Site 1	Site 2
Total Direct Costs (excluding decommissioning)[38]	Discrete distribution $44 million (20 %) $60.3 million (40 %) $109 million (40 %)	Discrete distribution $58 million (20 %) $66 million (40 %) $158 million (40 %)
Indirect	Discrete distribution $13 million (20 %) $18 million (40 %) $33 million (40 %)	Discrete distribution $58 million (20 %) $19.7 million (40 %) $158 million (40 %)
Operations, Maintenance and Repair (annual starting in year 4)	Gaussian (Normal) Distribution Mean – $0.611 million St Dev. – $0.050 million	Gaussian (Normal) Distribution Mean – $0.570 million St Dev. – $0.030 million
Decommissioning (Treated as one-time OMR cost at year 3)	Discrete distribution $1.7 million (25 %) $2 million (50 %) $3 million (25 %)	Discrete distribution $1.7 million (25 %) $2 million (50 %) $3 million (25 %)

Applying uncertainty to the modifications in the externalities is not obvious. For each simulation, they should be equivalent to the corresponding non-discounted annual value for whatever the sum of the simulated values for direct, indirect, and the response and recovery costs is. However, the underlying code does not allow this at present. There are multiple ways to attempt to handle the modifications for the uncertain inputs, though none provide "perfect" modifications for any

[37] Calculated assuming 2000 ambulance trips a year over the reduction of 1 km per trip and an increased chance of mortality of 1 % per 10 km.
[38] Ranges for the discrete distribution are based on a survey of completed hospital construction projects.

simulated values that need to be removed from the analysis. Knowing the issues with including uncertainty in situations with complex timing of cash flows, it may be best to forego the uncertainty analysis in the current version of EDGeS. Future versions may add the functionality to allow a more appropriate treatment of cash flows and dependence between distributions.

One option would be simply to not add uncertainty to the modifications and instead replace them with the mean of the underlying loss distributions. Alternatively, the distribution data for each loss reduction input may be input for the negative externalities. Copying in data from Table B.10 into the externality input for each year that requires modification would achieve this aim.

Table B.10 Uncertainties for flood related benefits for each hospital site

Loss Reduction Category	Site 1	Site 2
Direct	Triangular distribution Min - $18.75 million Most Likely - $22.5 million Max - $26.25 million	Triangular distribution Min - $23 million Most Likely - $27.5 million Max - $32 million
Indirect	Triangular distribution Min - $227 million Most Likely - $250 million Max - $273 million	Triangular distribution Min - $245 million Most Likely - $271 million Max - $297 million
Response and Recovery (Mold Remediation)	Gaussian (Normal) Distribution Mean - $18.0 million St Dev. - $1.2 million	Gaussian (Normal) Distribution Mean - $19.0 million St Dev. - $1.3 million
Response and Recovery (Evacuation)	Gaussian (Normal) Distribution Mean - $0.075 million St Dev. - $0.005 million	Gaussian (Normal) Distribution Mean - $0.075 million St Dev. - $0.005 million
Response and Recovery (Evacuation)	Gaussian (Normal) Distribution Mean - $2.2 million St Dev. - $0.250 million	Gaussian (Normal) Distribution Mean - $2.2 million St Dev. - $0.250 million

If there are too many loss reductions to make inputting modifications individually convenient, or there is concern the proliferation of inputs may slow down computation time, Lyapunov's Central Limit Theorem[39] (LCLT) may be used, provided the corresponding conditions are met. Using LCLT takes advantage of the fact that the mean of the distribution of the sum of a series of independent random variables is:

$$E[S_n] = E[X_1 + X_2 + \cdots + X_n] = E[X_1] + E[X_2] + \cdots + E[X_n]$$

Where S_n is the sum of random variables, $X_1, X_2, \ldots, X_n$. The variance will then be defined as:

[39] Lindeberg's condition could also be used, however meeting Lyapunov's condition implies that Lindeberg's is met and Lyapunov's condition is often slightly easier to calculate.

$$var(S_n) = \sum_{k=1}^{n} var(X_k) + \sum_{\substack{j=1 \\ j \neq k}}^{n} \sum_{k=1}^{n} cov(X_j, X_k)$$

If the underlying distributions are independent, then:

$$\sum_{\substack{j=1 \\ j \neq k}}^{n} \sum_{k=1}^{n} cov(X_j, X_k) = 0$$

and

$$var(S_n) = \sum_{k=1}^{n} var(X_k)$$

Since all distributions are assumed independent in the current version of the EDGeS, LCLT allows a normal distribution of the calculated mean and variance to be used.

In this example, the mean of each distribution is used without uncertainty. All distributions for flood related benefits are symmetric, so the point estimate sums are equivalent to the sum of the means. No such consideration is required for fatalities averted as there is no uncertainty input for them in the current version of the EDGeS. Table B.11 presents the non-disaster related benefits under uncertainty. All values for *Min*, *Max*, and *St. Dev.* are assumed without justification excluding the values for resale of the hospital, which is based on a literature survey of sale prices for decommissioned hospitals.

Table B.11 Non-disaster related benefit uncertainties for each hospital site

Non-disaster related benefit	Site 1	Site 2
Medical Error Reduction (Annual starting in year four)	Rectangular distribution Min - $15.8 million Max - $47.4 million	Rectangular distribution Min - $11.85 million Max - $19.75 million
Decrease in nosocomial infections (non-fatal) (Annual starting in year four)	Triangular distribution Min - $0.122 million Most Likely - $0.272 million Max - $0.422 million	Triangular distribution Min - $0.054 million Most Likely - $0.204 million Max - $0.354 million
Sale of old hospital	Rectangular distribution Min - $1.5 million Max - $2.5 million	Rectangular distribution Min - $1.5 million Max - $2.5 million
Reduction in travel distance (Annual starting in year four)	Gaussian (Normal) Distribution Mean – $0 million St Dev. – $2.63 million	Gaussian (Normal) Distribution Mean – $15.8 million St Dev. – $3.95 million

Interpreting Results

The EDGeS output in Table B.12 summarizes all pertinent output for the Point Estimate Analysis. In this case the non-event related economic benefits are larger than all others. Considering the VSL used and the rate of statistical lives saved this is not unexpected. Both options end up being a net positive in terms of NPV, with Site 1 being slightly better by roughly one million USD. Realistically speaking one million USD would be well within the expected error margin, so the two are essentially equal in NPV, as well as in all other economic indicators. Output related to *Without* Externalities is meaningless in this analysis due to the use of externalities to correct for the timing of cash flows.

The 31 million USD and 32.5 million USD represents the value of the correction applied to the analysis. This is the amount of additional benefits that would erroneously be accrued by not removing the benefits for the first three years. In practice, the two could be considered equivalent in terms of preference. In such a situation, the determining factor may be political, logistical, or based on some other economic factor. It could be argued that *Site 1* is preferable because, while the LCC suggests indifference, the first costs are lower, which may be an easier sell based on budget constraints.

The intermediate output from the analysis under uncertainty is provided in Table B.13, Table B.14 contains the economic indicator output from EDGeS. *Lower* and *Upper* bounds represent those values required for a 95 % prediction interval, i.e. 95 % confidence interval on the output values from the simulation. They are not confidence intervals on the mean. The point estimate in not the mean of the simulations, but the result of the point estimate calculations summarized in Table B.12.

Adding uncertainty to the analysis clarifies the desired outcome in this instance, although it is important to bear in mind the previous notes on the application of uncertainty related to the use of the correction for cash flow timing. All indicators including externalities suggest that *Site 1* is preferable at the upper bound, and only the lower bound of *Non-Disaster ROI* is better for *Site 2*. *Site 1* also has a higher upper prediction interval at $491 million ($90 million larger than the upper bound for *Site 2*) and its lower prediction interval only slightly lower than the one for *Site 2* by roughly $10 million.

Table B.12 EDGeS results for each hospital site using point estimates

	Site 1 (Suburb)	Site 2 (City Center)
Disaster Economic Benefits		
Response and Recovery Costs	$4 700 332	$4 960 378
Direct Loss Reduction	$5 851 036	$7 151 266
Indirect Losses	$65 583 615	$71 044 582
Disaster Non-Market Benefits		
Value of Statistical Lives Saved	$82 174 553	$82 174 553
Number of Statistical Lives Saved	80	80
Non-disaster Related Benefits		
One-Time	$1 452 298	$1 452 298
Recurring	$300 891 247	$300 250 361
Costs		
Direct Costs	$60 300 000	$65 670 000
Indirect Costs	$18 090 000	$19 700 000
OMR		
One-Time	$1 573 256	$1 573 256
Recurring	$5 758 858	$5 381 228
Externalities		
Positive		
One-Time	$0	$0
Recurring	$0	$0
Negative		
One-Time	$31 203 796	$32 587 215
Recurring	$0	$0
Present Expected Value		
Benefits	$460 653 081	$467 033 440
Costs	$85 722 113	$92 324 483
Externalities	($31 203 796)	($32 587 215)
With Externalities		
Net	$343 727 172	$342 121 741
Benefit-to-Cost Ratio	5.01	4.71
Internal Rate of Return (%)	26.13	25.04
Return on Investment (%)	2.94	2.74
Non-Disaster ROI (%)	1.59	1.42
Without Externalities		
Net	$374 930 968	$374 708 956
Benefit-to-Cost Ratio	5.37	5.06
Internal Rate of Return (%)	31.29	29.94
Return on Investment (%)	4.37	4.06
Non-Disaster ROI (%)	2.53	2.27

Table B.13 Intermediate EDGeS results for each hospital site under uncertainty[40]

	Site 1 (Suburb)			Site 2 (City Center)		
	Point Estimate	Lower Bound	Upper Bound	Point Estimate	Lower Bound	Upper Bound
Disaster Economic Benefits						
Response and Recovery Costs	$4 700 332	$4 090 814	$5 319 415	$4 960 378	$4 313 715	$5 637 252
Direct Loss Reduction	$5 851 036	$5 099 508	$6 600 024	$7 151 266	$6 250 401	$8 071 386
Indirect Losses	$65 583 615	$60 965 408	$70 236 522	$71 044 582	$65 775 548	$76 387 748
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	$82 174 553	$82 174 553	$82 174 553	$82 174 553	$82 174 553	$82 174 553
Number of Statistical Lives Saved	80.00	80.00	80.00	80.00	80.00	80.00
Non-disaster Related Benefits						
One-Time	$1 452 298	$1 108 098	$1 799 425	$1 452 298	$1 108 272	$1 796 672
Recurring	$300 891 247	$147 558 123	$458 103 369	$300 250 361	$216 772 825	$384 603 070
Costs						
Direct Costs	$60 300 000	$44 000 000	$109 000 000	$65 670 000	$58 000 000	$158 000 000
Indirect Costs	$18 090 000	$13 000 000	$33 000 000	$19 700 000	$17 400 000	$47 400 000
OMR						
One-Time	$1 573 256	$1 337 267	$2 359 884	$1 573 256	$1 337 267	$2 359 884
Recurring	$5 758 858	$4 824 266	$6 689 972	$5 381 228	$4 824 101	$5 948 485
Externalities						
Positive						
One-Time	$0	$0	$0	$0	$0	$0
Recurring	$0	$0	$0	$0	$0	$0
Negative						
One-Time	$31 203 796	$31 203 796	$31 203 796	$32 587 215	$32 587 215	$32 587 215
Recurring	$0	$0	$0	$0	$0	$0

[40] These values will differ based on the selected "Seed" and "Monte Carlo Bounds Tolerance" values on the "Analysis Information" pages

Table B.14 Economic Indicator EDGeS results for each hospital site under uncertainty[41]

	Site 1 (Suburb)			Site 2 (City Center)		
	Point Estimate	Lower Bound	Upper Bound	Point Estimate	Lower Bound	Upper Bound
Present Expected Value						
Benefits	$460 653 081	$307 315 993	$618 033 252	$467 033 440	$382 630 103	$551 570 932
Costs	$85 722 113	$65 124 201	$150 044 445	$92 324 483	$82 895 501	$213 060 091
Externalities	($31 203 796)	($31 203 796)	($31 203 796)	($32 587 215)	($32 587 215)	($32 587 215)
With Externalities						
Net	$343 727 172	$157 622 166	$491 708 712	$342 121 741	$169 202 420	$411 331 360
Benefit-to-Cost Ratio	5.01	2.06	7.67	4.71	1.82	5.68
Internal Rate of Return (%)	26.13	14.58	33.52	25.04	12.88	27.91
Return on Investment (%)	2.94	0.87	4.59	2.74	0.71	3.39
Non-Disaster ROI (%)	1.59	-0.06	3.05	1.42	0.01	2.01
Without Externalities						
Net	$374 930 968	$188 825 962	$522 912 507	$374 708 956	$201 789 635	$443 918 576
Benefit-to-Cost Ratio	5.37	2.27	8.13	5.06	1.98	6.06
Internal Rate of Return (%)	31.29	16.95	40.44	29.94	14.41	33.37
Return on Investment (%)	4.37	1.27	7.13	4.06	0.98	5.06
Non-Disaster ROI (%)	2.53	0.16	4.82	2.27	0.18	3.13

[41] These values will differ based on the selected "Seed" and "Monte Carlo Bounds Tolerance" values on the "Analysis Information" pages

B.2. *Buyout/Levee* Case Study

The purpose of the *Buyout/Levee* case study is two-fold. First it is meant to illustrate potential pitfalls that a user may fall into, and second, it illustrates a method for dealing with disasters where events of lesser or greater magnitude are relevant to the case study. Uncertainty is omitted in this case study to keep the interpretation of results simple, better illustrating the impacts of the various pitfalls discussed.

<u>Narrative</u>

After a 100-year flood hits a city, the CPT decides to adopt a flood mitigation strategy. After a study, two mutually exclusive alternatives emerge as realistic for the city to pursue: 1. buyout all properties in the 100-year floodplain and turn the area into greenspace; 2. build a 1.5-mile-long levee designed to work for a 100-year flood. To select the most economic option, an economic analysis is commissioned on each alternative. Regardless of the option, it is assumed that 25 % of the purchased homes do not return to the city's tax base.[42]

The mitigation measure would be focused in a residential area with a high-risk of flooding, and within the 100-year flood plain. The area consists of 600 homes in total (average value of $130 000 (Realtor.Com)), with 100 being considered waterfront properties (average value $190 000 (Krause 2014))[43]. The buyout option would require all homes to be purchased, while the levee would require all 100 waterfront properties, and 100 additional properties, be purchased to make room for levee construction. Two hundred of the homes, including all homes in the levee construction area, are eligible for FEMA grants which cover 75 % of the cost (Federal Emergency Management Agency 2014). The tax rate on all properties is 1.52 % (Smith 2014, Feb 4). A planning horizon of 75 years and a 5 % discount rate are assumed. The initial step in the analysis was to determine the total losses because of the flood. Table B.15 outlines these losses.

[42] For the sake of simplicity, the analysis foregoes an examination of the large economic impact of potentially losing 175 households from the city. This is a real concern however and in a true analysis should not be ignored. For this case study, it may be assumed that, although these homes leave the tax base, they remain close enough to continue to work in and add equivalent value to the city.

[43] For the purposes of this example fluctuations in home value, appreciation, and other time varying aspects of home value are omitted for simplicity.

Table B.15 Losses from flood

Category	Item	Value
Direct	Structural Losses	Waterfront – 90 % of value (Hallegatte 2015) Construction area – 75 % of value (Hallegatte 2015) All other – 50 % of value (Hallegatte 2015)
Direct	Evacuation	$1 982 148 (Pfurtscheller and Schwarze 2008)
Indirect	Relief	$11 100 027 (Pfurtscheller and Schwarze 2008)
Replacement and Repair	Clean up	$2 775 007 (Pfurtscheller and Schwarze 2008)
Fatalities	Lives lost (value of statistical life)	15 (assumed) ($7.9 million)

Assumptions

The following values are assumed for both alternatives:

Planning horizon – 75 years
Recurrence rate of Flood Event – 100 years
Real discount rate – 5 %
Value of a statistical life - 7 900 000 USD

Other key assumptions have been made to simplify the example. These are not necessarily realistic and should not be considered prescriptive for an actual LCC analysis.

1. Both alternatives function as designed for a 100-year flood, meaning no structural damage, and the assumed floodplain and disaster magnitude are accurate
2. Evacuations would still be required in the event of a 100-year flood for precautionary purposes
3. All one-time costs occur in year zero, while OMR costs first occur in year one and repeat annually
4. The analysis compares all values relative to the implicit option of doing nothing.

Assumptions related to specific values derived for the analysis are mentioned as they arise from the narrative.

Cost Data

The expected costs of each mitigation measure are found in Table B.16.

Table B.16 Costs for each mitigation measure

Category	Item	Buyout Value	Levee Value
Direct	Buyout of homes[44]	$59 897 500	$31 590 000
Direct	Structure demolition	$12 000 per home (improvenet)	$12 000 per home (improvenet)
Direct	Construction of greenspace	$200 000 (Cape Gazette 2016, Apr 27)	-
Direct	Levee design	-	15 % of construction cost (USACE 1982)
Direct	Levee construction	-	$10 million/mile (Koch 2010)
Indirect	Indirect (as percentage of pertinent direct costs)	30 %[45] (assumed)	30 %[46] (USACE 1982)
Operations, maintenance, and repair (OMR)	OMR costs on pertinent items	$15 000 per year (North Carolina State 2015, CNLM 2004)	$63 871 per year (Fairfax County, Virginia Government 2008)

<u>Benefit Data</u>

Event Related Benefits (*Benefits* screen in EDGeS)

In this case the community estimated all event-related benefits as the percentage reductions of the 100-year flood loss value given in Table B.17. While these values are beneficial for a 100-year flood, only using these loss reductions ignores a vital aspect of the proposed flood mitigation strategy: A mitigation measure that reduces the effects of a 100-year flood would also reduce the effects of lesser floods and potentially larger floods, depending on the nature of the event and the qualities of the mitigation measure. The question is how to incorporate these other impacts into the analysis if the data to incorporate them is available at all.

[44] This assumes there is no pushback from the community, litigation, or other costs that commonly arise due to the acquisition of private land by a governmental entity. These could be included in a more realistic model. Also, this value accounts for the 75% reduction in costs from FEMA grant eligible properties.
[45] 30 % of Greenspace construction and Structure demolition only
[46] For all direct costs excluding the buyout of homes

Table B.17 Percent reduction in losses for a 100-year flood for each option

Category	Item	Buyout Value	Levee Value
Direct Loss Reduction	Structural Losses	100 %	100 %
Direct Loss Reduction	Evacuation	80 %	33 %
Indirect Loss Reduction	Relief	80 %	85 %
Replacement and Repair Loss Reduction	Clean up	35 %	75 %
Fatalities Loss Reduction	Fatalities averted (value of statistical life)	18 Statistical Lives	19 Statistical Lives

Correcting for the missing benefits is not a trivial task. The first thought might be to simply run an analysis for a flood of every recurrence rate, i.e. a 1-year flood, a 2-year flood, a 3-year flood, and so on up to the design level of the mitigation measure and aggregating the results. There are multiple problems with this though.

First, running 100 analyses is inefficient and unnecessarily time consuming. This can be easily overcome with a conversion of on-flood reductions to an equivalent yearly rate (this will be illustrated later). The second problem is the nature of the one-year increments. In theory, a 99-year flood and a 100-year flood are distinct events, in reality they may be indistinguishable from one another. Lastly, data for floodplains generally does not exist for every single recurrence rate. The typically available values are the 10-year, 25-year, 50-year, and 100-year floodplains. GIS technology does allow for filling in gaps in the floodplain, but access or knowledge on how to use the software is not universal. Running an analysis for only those known flood plains may be feasible, but creates a risk of double counting inputs and could lead to a convoluted analysis when using EDGeS.

Considering these limitations, a possible path forward is to look at recurrence rates that are typically used in design and planning, in this case the 10-year, 25-year, 50-year, and 100-year floodplains and converting them into an equivalent annual rate of loss reduction. The first step is to determine the loss reductions for each design flood. In this case, it was assumed that flood losses followed an exponential growth trend per Eq. B-2. The assumed relationship between loss and recurrence rate should not be considered prescriptive and in practice, actual damage estimates based on floodplain maps, parcel values, and insurance information should be used to produce a realistic estimate. Equation B-2 is only assumed for convenience in illustrating the methodology.

$$L(t) = 549245 * 1.0617^t \qquad \text{(B-2)}$$

This amounts to a 10-year flood producing a loss value[47] of 1 000 000 USD. Based on this the losses for all design floods are calculated (Table B.18), as well as the additional reductions over the last recurrence rate. The expected number of each type of event in a year is calculated under the assumption of a Poisson process used by EDGeS. The loss value should realistically reach a ceiling value after a certain point. This would correspond to a complete loss of everything in the town. For the purposes of this example that value is assumed to be twice the 100-year flood loss value, and this ceiling occurs for a 200-year flood. Using the loss values in Table B.18 assumes that the town experiences the total loss possible for each expected flooding event. This may not necessarily be true, as a small flood following a larger flood within a short time frame may result in no additional losses, or a larger flood following a smaller flood may have a smaller loss value due to any unrecovered losses from the previous flood. There may be means of doing so, possibly using renewal functions and probabilistic time to repair coupled with a probabilistic model of flooding.

Table B.18 Expected losses from common design floods based on Eq. B-2

Recurrence Rate	Expected number of events in one year	Loss Value
10	0.1	$1 000 000
25	0.04	$2 456 691
50	0.02	$10 988 407
100	0.01	$219 838 182
200	0.0067	$439 676 364

Converting these to an equivalent yearly rate for EDGeS relies on the Poisson process assumption. It can be shown that the expected value of a flood of with a recurrence rate between some lower rate (more frequent event, E_1) and some upper rate (less frequent event, E_2) under a Poisson process is:

$$E[E_1 \leq E_x \leq E_2] = \left(\frac{1}{R_1} - \frac{1}{R_2}\right) * h \qquad \text{(B-3)}$$

Where: R_1 is the recurrence rate of E_1, R_2 is the recurrence rate of E_2, and h is the planning horizon. The expected number of events for a flood with a recurrence rate of 10 years on a flood with a recurrence rate of 25 years for a 75-year planning horizon would be:

$$E[E_1 \leq E_x \leq E_2] = \left(\frac{1}{10} - \frac{1}{25}\right) * 75 = 4.5$$

An estimate for the loss for a flood between these two values would then be, assuming the average loss for the two years, is:

[47] From this point on in Appendix B.2, “loss” refers to all event-related benefits (direct, indirect, response and recovery). These could be broken out individually for each subset of loss reductions if desired.

$$4.5 * \frac{\$1\ 000\ 000 + \$2\ 456\ 691}{2} = \$7\ 777\ 555$$

Table B.19 carries the average loss calculation out until it reaches asymptotic behavior.

Table B.19 Total loss value from common design floods based on Eq. B-2

Event Bounds	Expected number of events in planning horizon	Expected total value of loss in planning horizon
1-year[48] to 10-year	67.5	$33 750 000
10-year to 25-year	4.5	$7 777 555
25-year to 50-year	1.5	$10 083 824
50-year to 100-year	0.75	$86 559 971
100-year to 200-year	0.375	$123 658 977
200-year and up	0.375	$123 658 977

Assuming the percentage reductions for each time frame in Table B.20 hold[49], then the annualized loss reduction can be calculated by reducing the expected loss for each range according to the assumed percentages, summing the result and dividing by the planning horizon. Based on the loss reduction assumption for a 200-year and higher flood, there is no need to include it in the analysis, as neither option is treated as providing any benefit. The non-discounted annualized loss reductions are 2 510 425 USD for the buyout option and 2 277 728 USD for the levee option[50].

Table B.20 Assumed percent loss reductions of losses from Table B.19 for each mitigation measure

Event Bounds	Percent loss reduction Levee	Percent loss reduction Buyout
1-year[51] to 10-year	99 %	99 %
10-year to 25-year	97 %	95 %
25-year to 50-year	96 %	89 %
50-year to 100-year	95.7 %	80 %
100-year to 200-year	80 %[52]	75 %
200-year and up	0 %[53]	0 %

Fatalities Averted

[48] Assumed loss value of zero
[49] These values are all assumed without any justification.
[50] Going through the process to obtain these values presents a more complete depiction of benefits, but may be infeasible where the required loss data are absent. In such cases an analysis can be run looking only at the design disaster with the understanding that there may be uncaptured benefits and losses.
[51] Assumed loss value of zero
[52] Assumes levee overtopping, but not failure
[53] Assumes levee failure under a flood larger than a 200-year flood

A similar process is required for the value of statistical lives saved. The data required for this is presented in Table B.21. Going through the same procedure as for the loss reduction value, the statistical lives saved are 0.40 and 0.48 statistical lives per year for the buyout and levee respectively.

Table B.21 Data required to obtain equivalent annual fatalities averted for each mitigation measure

Recurrence Rate	Statistical Lives Lost	Buyout – Statistical Lives Saved	Levee – Statistical Lives Saved
10	0	0	0
25	2	1	2
50	5	3	3
100	15	13	14
200	35	15	16

Non-Disaster Related Benefits (Resilience Dividend)

Along with the on-flood benefits of each measure, the effects of measure on non-flood items was determined. The greenspace created by the buyout is expected to increase day visitors and overnight visitors by 22 % (48 USD per visit) and 26 % (107 USD per visit) respectively (Harnik and Welle 2009). Current estimate for the city are 10 000 overnight visitors and 15 000 day visitors per year. Table B.22 summarizes these values. The greenspace, while removing the value of any waterfront homes, should increase the value of the homes that now abut it, offsetting some of the lost waterfront tax revenue.

Table B.22 Non-disaster related benefits for each mitigation measure

Item	Buyout	Levee
Lost tax revenue[54]	$367 042 per year	$120 042 per year
Value of greenspace (as increase in tax revenue in nearby homes)	$9 880 per year (Harnik and Welle 2009)	-
Increase in visitors	$1 468 200 per year	-

Externalities

The major externality for the levee involves downstream flow. During a flood, any water that fails to flood the town makes its way downstream, potentially making flooding worse further downriver. A rough estimate found that, for every dollar saved by the levee, 5 cents[55] of

[54] The analysis focused on tax revenue generated by homes, though total home value could also be used just as easily. Doing so will change the final NPV and other key economic indicators, so it is important to define not only what key variables are important, but the appropriate way to measure them.
[55] This value is entirely fictional. There is no comprehensive literature on the economic impacts of increased downstream flooding due to upstream levees.

additional damage that would not have been experienced downstream occurs. The additional damage is translated to an annual cost as follows:

$$E_A = L_E * 0.05 = \$2\ 277\ 728 * 0.05 = \$113\ 886$$

Where E_A is the annual externality of downstream damage. L_E is the non-discounted annualized loss reduction, and 0.05 is the dollars downstream loss to dollar loss prevented ratio. There is no need to divide by the planning horizon as the non-discounted annualized loss reductions are already annualized values.

Greenspace externalities typically involve increased tourism and environmental benefits. As increased tourism has been internalized in the analysis, it is no longer an externality. Many environmental aspects are already captured by the value of the greenspace on property value, however such hedonic pricing techniques fail to capture the impact on storm water management[56]. The use of greenspace is estimated to save roughly 200 000 USD annually in reduced wastewater pumping costs (Greater Dallas Planning Council 2015).

EDGeS Inputs

The following values are assumed for both alternatives. Note that the recurrence rate is now 1-year, due to the process of determining an equivalent annual rate.

Planning horizon – 75 years
Recurrence rate of Flood Event – 1 year
Real discount rate – 5 %
Value of a statistical life - 7 900 000 USD

The cost inputs for EDGeS are summarized in Table B.23. Operations, maintenance, and repair costs start accruing in year 1.

Table B.23 Cost input values for EDGeS for each mitigation measure

Cost Category	Cost	Buyout	Levee
Direct	Purchase of Homes	$59 897 500	$31 590 000
	Structure Demolition	$5 400 000	$2 400 000
	Levee Design	-	$2 250 000
	Levee Construction	-	$15 000 000
	Greenspace construction	$200 000	-
Indirect	Indirect Costs	$1 680 000	$4 500 000
OMR	OMR Costs	$15 000 annually	$63 871 annually

[56] Other known benefits include reducing peak flows during storms and higher water quality, but for simplicity only the storm water management aspect was included in the analysis. In practice, all realistic costs and benefits must be included to ensure an accurate and meaningful analysis.

On-disaster benefits are presented in Table B.24. These values represent the equivalent yearly loss reductions. The *Total Loss Reduction* values can be entered as any cost category in EDGeS since they are not broken out by *Direct*, *Indirect*, or *Response and Recovery*.

Table B.24 Flood related loss reduction input for EDGeS for each mitigation measure

Loss Category	Buyout	Levee
Total Loss Reduction	$2 510 425	$2 277 728
Fatalities Averted	0.40	0.48

Non-disaster related benefit inputs are presented in Table B.25. Externality inputs are found in Table B.26. Both NDRBs and externalities are assumed to begin accruing in year one.

Table B.25 Non-disaster related benefit input for EDGeS for each mitigation measure

Item	Buyout	Levee
Tax revenue[57]	($367 042) annually	($120 042) annually
Value of greenspace (as increase in tax revenue in nearby homes) [14]	$9880 annually	-
Increase in visitors	$1 468 200 annually	-

Table B.26 Externality input for EDGeS for each mitigation measure

Externality (Positive/Negative)	Buyout	Levee
Additional downstream damage (Negative)	-	$113 886 annually Owner – Downstream Communities
Reduced storm water management (Positive)	$200 000 annually Owner – Water Utility	-

Interpreting Results

Results using only a 100-year flood

While using only the 100-year flood data omits potential benefits and losses, it is not necessarily an error to use it as the basis for analysis and decision making. The amount of data to get equivalent annual losses may not be available or may be cost-prohibitive to obtain. In such instances, the use of the design event may be the only analysis that can feasibly be done.

Table B.27The results in Table B.27 indicate that the buyout is the preferable option, as its *NPV* is over three times that of the levee option. Both options also have positive *NPVs*, thus they are

[57] The analysis focused on tax revenue generated by homes, though total home value could also be used just as easily. Doing so will change the final NPV and other key economic indicators, so it is important to define not only what key variables are important, but the appropriate way to measure them.

better than the implicit *Do Nothing* option. Interestingly the levee option has a negative Non-disaster ROI, indicating that if no disaster occurs, the alternative may prove to be a loss.[58]

Table B.27 EDGeS results for each mitigation measure using only 100-year loss reductions

	Buyout	Levee
Disaster Economic Benefits		

[58] Public perceptions of increased safety notwithstanding.

Response and Recovery Costs	$194 464	$416 708
Direct Loss Reduction	$44 015 901	$44 015 901
Indirect Losses	$1 777 954	$1 889 076
Disaster Non-Market Benefits		
Value of Statistical Lives Saved	$20 562 547	$22 144 282
Number of Statistical Lives Saved	9.75	10.5
Non-disaster Related Benefits		
One-Time	$0	$0
Recurring	$21 160 244	($2 286 257)
Costs		
Direct Costs	$65 497 500	$51 240 000
Indirect Costs	$1 680 000	$4 500 000
OMR		
One-Time	$0	$0
Recurring	$285 682	$1 216 453
Externalities		
Positive		
One-Time	$0	$0
Recurring	$3 809 094	$0
Negative		
One-Time	$0	$0
Recurring	$0	$2 169 013
Present Expected Value		
Benefits	$87 711 110	$66 179 711
Costs	$67 463 182	$56 956 453
Externalities	$3 809 094	($2 169 013)
With Externalities		
Net	$24 057 022	$7 054 245
Benefit-to-Cost Ratio	1.30	1.20
Internal Rate of Return (%)	6.95	5.71
Return on Investment (%)	0.40	0.27
Non-Disaster ROI (%)	-0.92	-1.34
Without Externalities		
Net	$20 247 928	$9 223 257
Benefit-to-Cost Ratio	1.30	1.16
Internal Rate of Return (%)	6.64	5.93
Return on Investment (%)	0.40	0.22
Non-Disaster ROI (%)	-0.92	-1.39

Results using equivalent annual losses

If the data are available, and an equivalent annual loss value is obtained, EDGeS produces the output in Table B.28. While not true for all analyses, the final decision does not change with the inclusion of the additional flood related benefits. What does change is the magnitude of the *NPV*. The *NPV* with externalities increases by roughly 37 million USD for the buyout and 53 million USD for the levee. This in turn increases the overall *ROI, IRR,* and *BCR,* but not the *Non-Disaster ROI*. In the input phase, all event-related benefits were added together for the purposes of simplifying the process of obtaining the equivalent annual loss value, thus the on-disaster output is entirely found in the *Direct Loss Reduction* output.

A situation can easily be envisioned where an analysis using only the design disaster produces a negative *NPV* but inclusion of missing benefits and losses from other affected disaster magnitudes produces a positive *NPV*. This fact does not justify performing an analysis for a single design disaster and, assuming absent further analysis, that if all impacted disasters were incorporated the overall effect would be positive, even if the *NPV* of the single design disaster analysis was negative. Decisions should always be made based on available data and actual analysis, not unjustified assumptions.

Table B.28 EDGeS results for each mitigation measure using the equivalent annual loss reductions

	Buyout	**Levee**
Disaster Economic Benefits		
Response and Recovery Costs	$0	$0

Direct Loss Reduction	$50 263 616	$45 604 567
Indirect Losses	$0	$0
Disaster Non-Market Benefits		
Value of Statistical Lives Saved	$63 269 377	$75 923 252
Number of Statistical Lives Saved	30	36
Non-disaster Related Benefits		
One-Time	$0	$0
Recurring	$21 160 244	($2 286 257)
Costs		
Direct Costs	$65 497 500	$51 240 000
Indirect Costs	$1 680 000	$4 500 000
OMR		
One-Time	$0	$0
Recurring	$285 682	$1 216 453
Externalities		
Positive		
One-Time	$0	$0
Recurring	$3 809 094	$0
Negative		
One-Time	$0	$0
Recurring	$0	$2 169 013
Present Expected Value		
Benefits	$134 693 236	$119 241 563
Costs	$67 463 182	$56 956 453
Externalities	$3 809 094	($2 169 013)
With Externalities		
Net	$71 039 149	$60 116 097
Benefit-to-Cost Ratio	2.00	2.06
Internal Rate of Return (%)	10.73	10.99
Return on Investment (%)	1.33	1.36
Non-Disaster ROI (%)	-0.92	-1.39
Without Externalities		
Net	$67 230 054	$62 285 109
Benefit-to-Cost Ratio	2.00	2.09
Internal Rate of Return (%)	10.43	11.20
Return on Investment (%)	1.33	1.46
Non-Disaster ROI (%)	-0.92	-1.39

Results using only upfront costs

Using only upfront costs to base a decision with long-term cash flow considerations is difficult to justify. There are situations where alternatives will be limited by first costs, as budgets themselves are limited, but there should be a thorough examination of future costs and benefits where feasible.

There is no need to run EDGeS to obtain the results of using only first costs. The total first cost for the buyout option is 67 177 500 million USD and for the levee option is 55 740 000 million USD. The levee is the better option when using only first costs, but as was seen in the previous analysis, the better option when including future cash flows is the buyout. Losing the future costs and benefits erases all the good and bad that come from each option through their design lives. Not only does this result in an inaccurate model of the economics of the alternative, it can also lead to poor decision making.

Results omitting NDRBs (The Resilience Dividend)

Traditionally only those costs and benefits related to mitigating the effects of an event are examined when analyzing disaster mitigation options. This ignores the potential for co-benefits to accrue for certain options. Co-benefits should not take precedent over reliability or feasibility concerns, but do provide some economic relief (or additional burden) to any costs incurred by each option which may be of economic value and worth consideration. Table B.29 illustrates what happens to the *Buyout/Levee* decision when NDRBs are omitted. This analysis uses the equivalent annual loss reductions, a similar analysis could be done using only the 100-year flood losses.

Lacking the future NDRBs to offset the higher initial costs of the buyout, the preference is flipped. While both options still make economic sense *NPV*-wise, the additional economic benefit that could be gained from the buyout are lost and they are non-trivial, totaling around 21 million USD. The decision made omitting NDRBs isn't necessarily wrong, it is however incomplete and potentially results in the loss of real financial benefits.

Table B.29 EDGeS results for each mitigation measure omitting NDRBs

	Buyout	**Levee**
Disaster Economic Benefits		
Response and Recovery Costs	$0	$0

Direct Loss Reduction	$50 263 616	$45 604 567
Indirect Losses	$0	$0
Disaster Non-Market Benefits		
Value of Statistical Lives Saved	$63 269 377	$75 923 252
Number of Statistical Lives Saved	30	36
Non-disaster Related Benefits		
One-Time	$0	$0
Recurring	$0	$0
Costs		
Direct Costs	$65 497 500	$51 240 000
Indirect Costs	$1 680 000	$4 500 000
OMR		
One-Time	$0	$0
Recurring	$285 682	$1 216 453
Externalities		
Positive		
One-Time	$0	$0
Recurring	$3 809 094	$0
Negative		
One-Time	$0	$0
Recurring	$0	$2 169 013
Present Expected Value		
Benefits	$113 532 993	$121 527 819
Costs	$67 463 182	$56 956 453
Externalities	$3 809 094	($2 169 013)
With Externalities		
Net	$49 878 905	$62 402 353
Benefit-to-Cost Ratio	1.68	2.10
Internal Rate of Return (%)	9.09	11.21
Return on Investment (%)	0.91	1.41
Non-Disaster ROI (%)	-1.33	-1.33
Without Externalities		
Net	$46 069 810	$64 571 366
Benefit-to-Cost Ratio	1.68	2.13
Internal Rate of Return (%)	8.79	11.41
Return on Investment (%)	0.91	1.51
Non-Disaster ROI (%)	-1.33	-1.33

Results with a 0 % discount rate

Whereas the other analyses in this section have shown the effects of omitting or losing the importance of benefits, assuming a discount rate of zero has the opposite effect. The assumption behind a zero-discount rate is that a dollar at any future point in time is equivalent to a dollar now. This is an unrealistic assumption in almost any case where the time span is measured in years and drastically overstates the value of future losses and benefits. The results in Table B.30 illustrate this effect. The analysis uses the equivalent annual loss reduction values.

While the preference does not change, the *NPV* is exaggerated, with an increase of over 7 times the equivalent annual loss reduction *NPV* calculation for both alternatives. This is driven entirely by the loss reductions, which are now over 150 million USD from being roughly 50 million USD. The effect of value of statistical lives saved is also greatly exaggerated, rising by almost 200 million USD in both cases. Careful selection of the discount rate is necessary to ensure the results are meaningful however this value is dependent on the decision-maker(s).

Table B.30 EDGeS results for each mitigation measure using a 0 % discount rate

	Buyout	Levee

Disaster Economic Benefits		
Response and Recovery Costs	$0	$0
Direct Loss Reduction	$188 281 875	$170 829 600
Indirect Losses	$0	$0
Disaster Non-Market Benefits		
Value of Statistical Lives Saved	$237 000 000	$284 400 000
Number of Statistical Lives Saved	30	36
Non-disaster Related Benefits		
One-Time	$0	$0
Recurring	$83 327 850	($9 003 150)
Costs		
Direct Costs	$65 497 500	$51 240 000
Indirect Costs	$1 680 000	$4 500 000
OMR		
One-Time	$0	$0
Recurring	$1 125 000	$4 790 325
Externalities		
Positive		
One-Time	$0	$0
Recurring	$15 000 000	$0
Negative		
One-Time	$0	$0
Recurring	$0	$8 541 450
Present Expected Value		
Benefits	$508 609 725	$446 226 450
Costs	$68 302 500	$60 530 325
Externalities	$15 000 000	($8 541 450)
With Externalities		
Net	$455 307 225	$377 154 675
Benefit-to-Cost Ratio	7.45	7.32
Internal Rate of Return (%)	10.73	10.99
Return on Investment (%)	8.60	7.28
Non-Disaster ROI (%)	0.29	-1.51
Without Externalities		
Net	$440 307 225	$385 696 125
Benefit-to-Cost Ratio	7.45	7.37
Internal Rate of Return (%)	10.43	11.20
Return on Investment (%)	8.60	8.50
Non-Disaster ROI (%)	0.29	-1.53

B.3. *Wildland Urban Interface* Case Study

The purpose of the Wildland Urban Interface (*WUI)* case study is to illustrate the effects of altering the recurrence rate of a disaster. While not feasible for many other types of disasters, wildfire is a hazard whose severity can be managed through planned actions.

Narrative

Several towns in a WUI area recently had a wildland fire, with an estimated return rate of 25 years, burn near them. Smoke was a minor nuisance, and no evacuation was required nor were there any reported health impacts. Ultimately there was no damage to any property, nor any fatalities from the fire. The fire ended when a large rain storm passed through. In examining the impacts of the fire, one major issue was that it burned a riparian forest, and in the aftermath, a large amount of runoff went into the local river. The town relies on this river for drinking water, and the large amount of runoff has caused substantial issues.

Their treatment plant recorded a substantial increase in turbidity (400 %) over a 12-month period after the fire (Tecle and Neary 2015), greatly increasing treatment costs and hampering operations. Assuming a base cost of water treatment of 0.0198 USD per m^3 (75 per million gallons USD) and a 0.25 % increase in cost for each 1 % increase in turbidity (Dearmont et al. 1998), the cost of water treatment doubled. The towns in the region use roughly 402 000 m^3 (approximately 106 million gallons) per month (Southern California Public Radio 2017). Due to the fire, the treatment plant incurred an additional 95 515 USD in chemical costs. The increased turbidity also increased the amount of sludge the plant was required to dispose of, resulting in an increased cost of 1.9 million USD (Danahey 2017, Mar 27). All losses from the previous fire are provided in Table B.31.

Table B.31 Losses caused by increased erosion due to instigating fire

Loss Category	Description	Loss value
Direct	Increased water treatment chemical cost	$95 515
Direct	Increased sludge removal cost	$1.9 million (Danahey 2017, Mar 27)
Indirect	Recreational Value (Wildland Fire)	$77.71 per trip[59] (Hayley et al. 2003) 1500 trips lost after fire
Indirect	Additional indirect costs to water treatment plant	33 % of increase in direct costs (Zuzulock 2003)
Recovery and Replacement	Reseeding	$120 per acre (Reynolds and Sikole) for: 3000 acres

Worried that a larger fire could potentially inhibit the ability of the treatment plant to provide water, a proposal was put forward that the towns should seek assistance in managing the forest in their area. This would include an organized reconstruction of the riparian forest lost during the

[59] Based on weighted average of "time after burn" values for both hikers and bikers using forest land

fire, as well as management of adjacent forested areas to lessen the chances of a wildfire. The forested area in question is roughly 6000 acres, 500 of which are considered riparian.

The primary tactic for forest adjacent to riparian areas (roughly 1500 acres per burn (U.S. Forest Service a)) would be prescribed burns every four years for fuels management, while 50 acres of erosion susceptible riparian area would be reseeded and contoured with straw wattles to create an additional barrier to runoff. The reseeding itself is considered a recovery and replacement cost as it is required regardless of the management strategy. From an input perspective, this means only the reduction in reseeding cost needs to be entered into the analysis.

The sentiment among those opposed is that the treatment plant operated fine during the fire's aftermath and the fire events of the type that initiated the problem are sufficiently uncommon to justify the status quo. Unsure of whether to go forward an economic analysis was sought to compare the alternatives.

For the purposes of this example there are two alternatives, (1) do nothing or (2) go forward with the management plan above. The town uses a 4 % discount rate and is looking at a planning horizon of 50 years.

<u>Assumptions</u>

The following values are assumed for both alternatives:

Planning horizon – 50 years
Recurrence rate of Fire Event – 25 years (in base analysis)
Real discount rate – 4 %
Value of a statistical life – Not Applicable

Other key assumptions have been made to simplify the example. These are not necessarily realistic and should not be considered prescriptive for an actual LCC analysis.

1. There is a zero probability of a prescribed fire escaping containment or causing loss of life.
2. All areas covered by the effects water treatment plant are covered in the analysis
3. Future fires will be considered to occur in the same area, and thus would not threaten populated areas
4. The burn area is non-populated
5. There is no loss information on fires of lesser or greater magnitude. This assumption is made to avoid the consideration of other magnitude losses in the analysis akin to the example in Appendix B.2. The results are therefore a lower bound of the NPV.

Assumptions related to specific values derived for the analysis are mentioned as they arise from the narrative.

<u>Cost Data</u>

Table B.32 contains all the elements related to the cost of implementing the management plan.

Table B.32 Costs related to implementing the mitigation measure

Cost Category	Description	Cost
Direct	Straw wattles	\$2.87/ft^2 (homewyse 2017)
Indirect	Indirect costs of remediation	10 % of direct cost (U.S. Forest Service b)
OMR	Prescribed burn – fuels management	\$15.00 per acre (North Carolina Forest Service (NCFS) 2009) \$3.45 per mile for hauling[60] (NCFS 2009) \$100 per hour – tractor[61] (NCFS 2009) 10 % of direct costs as indirect costs (U.S. Forest Service b) Frequency – 4 years (Mobley 1973, U.S. Dept. of Agriculture) starting in year 4

Benefit Data

Event Related Benefits (*Benefits* screen in EDGeS)

Table B.33 contains the expected loss reduction from the mitigation measure. There is no loss reduction in *Recreation Value* in the event a wildfire occurs, under the assumption that it is primarily a psychological driver for keeping people away.

Table B.33 Estimated loss reductions from implementing the mitigation measure

Loss Category	Description	Loss Reduction
Direct	Increased water treatment chemical cost	\$83 576
Direct	Increased sludge removal cost	\$1.7 million
Indirect	Additional indirect costs to water treatment plant	33 % of direct loss reductions
Recovery and Replacement	Reseeding	\$120 per acre for: 1500 acres

Fatalities Averted

No fatalities were associated with the precipitating event, so there is no *Fatalities Averted* input.

60 Assumed 100 miles for hauling
61 Assumed 30 tractor hours, derived from tractor costs taken from [20]

Non-Disaster Related Benefits

There are concerns about the cost of the plan, and some of the area population are resisting the move, as it would require a tax increase and could potentially reduce the recreation value of the managed area. Recreational trips have a base value of 174.73 USD per trip (Englin et al 2008) and around 5000 trips per year (Planning, Recreation, and Support Section Marketing and Business Development Office). On the other hand, it is expected that the increased river health will increase the salmon population after a period of five years, and greatly improve watershed quality in 10 years. The relevant values are provided in Table B.34.

Table B.34 Non-disaster related benefits associated with the mitigation measure

Non-event item	Benefit
Recreational value (Prescribed burn)	$12.2 per trip[62] (Hayley et al 2003) with 750 fewer trips annually
Increased river health (salmon)	$308 per person[63] (Hanemann et al. 1991)
Increased river health (watershed)	$21 per person per month[64] (Loomis et al. 2000)

Externalities

No externalities are identified in this case. The entire coverage area of the water treatment plant is under consideration, and the area in question is far enough away that prescribed burns should not produce enough smoke to be a nuisance or cause health concerns. Any recreational value of the forest is accounted for, and the area is assumed non-populated, making hedonic price studies irrelevant. Potential externalities associated with a prescribed burn escaping containment are not considered in the current analysis.

<u>EDGeS Inputs</u>

Using the provided data, the inputs into EDGeS can be calculated.

Reduction in severity of a 25-year fire (*Method 1*)

The first analysis focuses on treating the effect of the mitigation measure as reducing the severity of a 25-year event. Non-monetized inputs are as follows:

Planning horizon – 50 years
Recurrence rate of Fire Event – 25 years (in base analysis)
Real discount rate – 4 %
Value of a statistical life – Not Applicable

[62] Based on weighted average of "time after burn" values for both hikers and bikers using forest land.
[63] Assumed effected population of 17 500 people
[64] Assumed effected population of 17 500 people

The inputs for cost are given in Table B.35. Operations, maintenance, and repair costs start accruing in year four.

Table B.35 Cost inputs into EDGeS for the mitigation measure

Description	Value
Direct	$6 250 860
Indirect	$625 086
Operations, Maintenance, and Repair	$28 430 every 4 years starting in year 4

The key area where the analyses differ, other than their return rate, is in how loss reductions are calculated. Table B.36 contains the loss reduction inputs for the first analysis, while non-fire related benefits are presented in Table B.37. Recreation value negative benefits start accruing in year one.

Table B.36 Loss reduction input into EDGeS for the mitigation measure

Loss Category	Description	Loss Reduction
Direct	Increased water treatment chemical cost	$83 576
Direct	Increased sludge removal cost	$1.7 million
Indirect	Additional indirect costs to water treatment plant	$588 580
Recovery and Replacement	Reseeding	$180 000

Table B.37 Non-disaster related benefit input for the mitigation measure

Non-event item	Benefit
Recreational value (Prescribed burn)	($51 850) annually[65]
Increased river health (salmon)	$4 620 000 one-time[66] At year: 5
Increased river health (watershed)	$3 780 000 one-time[67] At year: 10

Decreasing the frequency of the precipitating fire (*Method 2*)

[65] This represents the change in recreation value relative to the baseline for prescribed burns, like the case for wildland fires.

[66] It is assumed that the valuation is a one-time value, that is the value of increasing salmon population occurs only once

[67] It is assumed that the valuation is a one-time value, that is the value of improving the watershed quality occurs only once

Analyzing the fire from the perspective that the mitigation measure makes a pre-measure 25-year fire a less frequent event requires altering how the analysis is set up. All previous analysis assumed that the reduction in the severity of the event was the driving factor. That made it possible to obtain NPV values relative to this option as the recurrence rates were identical. Simply put, the option of doing nothing would theoretically have the same result as the previous disaster, so any loss values could be viewed as reductions to that value to simplify analysis. By changing the recurrence rate and assuming the disaster is now equivalent to the precipitating event, this is no longer the case. Both disasters are now equivalent in scale, so no loss reduction is expected to occur for the now less frequent event meaning the loss reduction is zero.

Accounting for the altered rate of recurrence means the relative losses of the disaster can no longer be used as the basis for comparison. Instead, the base case contains the total costs, benefits, externalities, and losses of the precipitating event assuming no mitigation takes place. The alternative event contains the total costs benefits, externalities, and losses of the event that now takes place at a lower frequency. Comparison is then done based on the total NPVs of each option.

It is assumed that any fire with lesser intensity than the one that caused the mitigation measure to be considered is insufficient to warrant any input considerations like those in Appendix B.2. This assumption violates the previous analysis, as reducing the impact of the 25-year fire was assumed to fail to completely negate event-related losses, but is done here regardless as it helps avoid masking the differences in the analyses under a more complex procedure.

For the purposes of the example, fires of greater magnitude are not expected to be effected by the mitigation measure. This leads to one of the major issues with this method, namely: What happens to what was once a 50-year fire if a 25-year fire becomes a 35-year fire? A 50-year fire could realistically also have its return period adjusted as could larger fires. For illustration purposes, such considerations are omitted in favor of illustrating the EDGeS steps required to adjust a recurrence rate in the program.

The other issue with the idea of altering the recurrence rate is: How does one know what the new recurrence rate is? It may be possible to look at other area’s mitigation measures and their effectiveness, however the data may not be available. Adjusting the recurrence rate is therefore highly questionable in practice, without a significant amount of data collection to fully understand how far it pushes out a fire’s recurrence, as well as all other fires of significant magnitude. Failing to do so paints an incomplete picture. The analysis that follows can be assumed to be a lower bound of the possible benefits from the mitigation measure, absent any loss data on other fires.

The save file must be altered directly to do this kind of analysis in EDGeS. EDGeS defaults to using the same return period for each plan. While the GUI does not allow the user to define different return periods, EDGeS is capable of handling it. See Appendix C for guidance on manually manipulating the save file.

Non-monetized inputs are as follows:

Planning horizon – 50 years
Recurrence rate of Fire Event (without mitigation) – 25 years
Recurrence rate of Fire Event (with mitigation) – 50 years[68]
Real discount rate – 4 %
Value of a statistical life – Not Applicable

Cost inputs are presented in Table B.38. As before OMR costs begin accruing in year four.

Table B.38 EDGeS inputs for costs for the two alternatives

Description	Without Mitigation	With Mitigation
Direct	$0	$6 250 860
Indirect	$0	$625 086
Operations, Maintenance, and Repair	$0	$28 430 every 4 years

Fire-related losses (Table B.39) are identical for each disaster, as the effect of the mitigation measure is now to simply push an identical fire further out in time. Thus, the values in Table B.39 are the total loss values for the originating fire. When a value is input into the *Benefits* page of EDGeS, it assumes that it is a loss reduction, and therefore treats it as a positive cash flow in the analysis. Each value in Table B.39 must be entered in as a negative value, since these values are now representing total losses. The Non-disaster related benefits in Table B.39 are only accrued by the mitigation option.

Table B.39 Total loss input into EDGeS for each alternative

Loss Category	Description	Loss value
Direct	Increased water treatment chemical cost	$95 515
Direct	Increased sludge removal cost	$1 900 000
Indirect	Recreational Value (Wildland Fire)	$116 565
Indirect	Additional indirect costs to water treatment plant	$658 520
Recovery and Replacement	Reseeding	$360 000

Table B.40 Non-disaster related benefit input into EDGeS for each mitigation measure

Non-event item	Without Mitigation	With Mitigation

[68] See Appendix B.3 for guidance on how to change the *Recurrence Rate* for an individual alternative.

Recreational value (Prescribed burn)	$873 650 annually	$821 800 annually[69]
Increased river health (salmon)	$0 [70]	$4 620 000 one-time[71] At year: 5
Increased river health (watershed)	$0 [72]	$3 780 000 one-time[73] At year: 10

Interpreting Results

Results under Method 1

EDGeS output for *Method 1* is presented in Table B.41. The mitigation measure is economical per the analysis, as its *NPV* is roughly $500 000 compared to the implicit alternative of doing nothing. All other indicators suggest that the project will be beneficial as well.

Table B.41 EDGeS output for Method 1

	Mitigation
Disaster Economic Benefits	

[69] This represents the change in recreation value relative to the baseline for prescribed burns, like the case for wildland fires.
[70] It is assumed that the salmon population remains constant if no mitigation takes place
[71] It is assumed that the valuation is a one-time value, that is the value of increasing salmon population occurs only once
[72] It is assumed that the watershed health remains constant if no mitigation takes place
[73] It is assumed that the valuation is a one-time value, that is the value of improving the watershed quality occurs only once

Response and Recovery Costs	$158 773
Direct Loss Reduction	$1 573 245
Indirect Losses	$519 171
Disaster Non-Market Benefits	
Value of Statistical Lives Saved	$0
Number of Statistical Lives Saved	0
Non-disaster Related Benefits	
One-Time	$6 316 346
Recurring	($1 098 555)
Costs	
Direct Costs	$6 250 860
Indirect Costs	$625 086
OMR	
One-Time	$0
Recurring	$139 830
Externalities	
Positive	
One-Time	$0
Recurring	$0
Negative	
One-Time	$0
Recurring	$0
Present Expected Value	
Benefits	$7 468 980
Costs	$7 015 776
Net	$453 204
Benefit-to-Cost Ratio	1.065
Internal Rate of Return (%)	4.79
Return on Investment (%)	0.13
Non-Disaster ROI (%)	-0.51

Results under Method 2

EDGeS output for *Method 2* is presented in Table B.42.

Table B.42 EDGeS output for Method 2

	No Action	Mitigation
Disaster Economic Benefits		
Response and Recovery Costs	($317 546)	($158 773)
Direct Loss Reduction	($1 760 190)	($880 095)
Indirect Losses	($1 161 726)	($580 863)
Disaster Non-Market Benefits		
Value of Statistical Lives Saved	$0	$0
Number of Statistical Lives Saved	0	0
Non-disaster Related Benefits		
One-Time	$0	$6 316 346
Recurring	$0	($1 098 555)
Costs		
Direct Costs	$0	$6 250 860
Indirect Costs	$0	$625 086
OMR		
One-Time	$0	$0
Recurring	$0	$139 830
Externalities		
Positive		
One-Time	$0	$0
Recurring	$0	$0
Negative		
One-Time	$0	$0
Recurring	$0	$0
Present Expected Value		
Benefits	($3 239 463)	$3 598 060
Costs	$0	$7 015 776
Net	($3 239 463)	($3 417 716)
Benefit-to-Cost Ratio	No Valid BCR	0.51
Internal Rate of Return (%)	No Valid IRR	No Valid IRR
Return on Investment (%)	No Valid ROI	-0.97
Non-Disaster ROI (%)	No Valid ROI	-0.51

Under Method 2, the *Net* value represents the total *NPV* whereas *Net* represented the *NPV* relative to the option of doing nothing for Method 1. The comparison procedure is still the same though, the larger *NPV* is preferable. The desirable option under Method 2 is to take no action, as its *Net* value is slightly higher. Note that both options are negative, indicating net loss regardless of which option is selected. This is akin to the discussion of *SIR* and *BCR* is Section 2.4.1. What is desired when looking at the total values from the disaster is greater cost reductions, meaning the total NPV may still be negative. Greater benefits are more pertinent when measuring loss reductions (net savings) relative to the baseline. This result is counter to the Method 1 analysis due to the differences in how the problem was framed.

Neither option has a valid *IRR*. This arises from either the value of the IRR being outside the bounds of the bracketing method used by the program, or the value not existing at all. The mitigation option has a negative *ROI* and *Non-Disaster ROI*, and a *BCR* less than one. Whether these alternative economic indicators affect the decision-making process is decision-maker dependent.

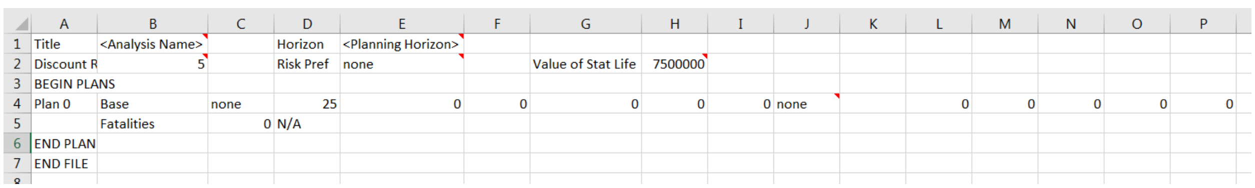
Appendix C. Spreadsheet Data Entry

This section will describe using the template files 'Input Template v2.xlsx' and 'Template Construction v2.xlsx' to create a save file for analysis without using the Graphical User Interface (GUI).

Only construct the input file from scratch if you are comfortable with working in Microsoft Excel and understand the that the input file follows certain strict rules that, if not adhered to, could result in severe errors or erroneous output.

Inputting project data through the GUI has the advantage of validating input as it is entered. Furthermore, any save files created by the GUI will lack the structural errors in save files to which this method may be prone. Some save file errors will keep the file from being read in or otherwise stop EDGeS, while others could pass through unseen. If you do not feel confident working with the save file directly, please use the GUI.

It is recommended that you save the 'Template' tab of the file 'Input Template v2' as a separate file (or copy it) to avoid accidentally writing over the template provided. These entries correspond to the *Project Information* page and the *Fatalities Averted* page of the GUI.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Title	<Analysis Name>		Horizon	<Planning Horizon>											
2	Discount R	5		Risk Pref	none		Value of Stat Life	7500000								
3	BEGIN PLANS															
4	Plan 0	Base	none	25	0	0	0	0	0	none		0	0	0	0	0
5		Fatalities	0	N/A												
6	END PLAN															
7	END FILE															

Figure C.1 Template tab

Your file now looks like Figure C.1. First, fill in rows 1 through 4. Except for H2, each of these cells saves data from the *Project Information* page.

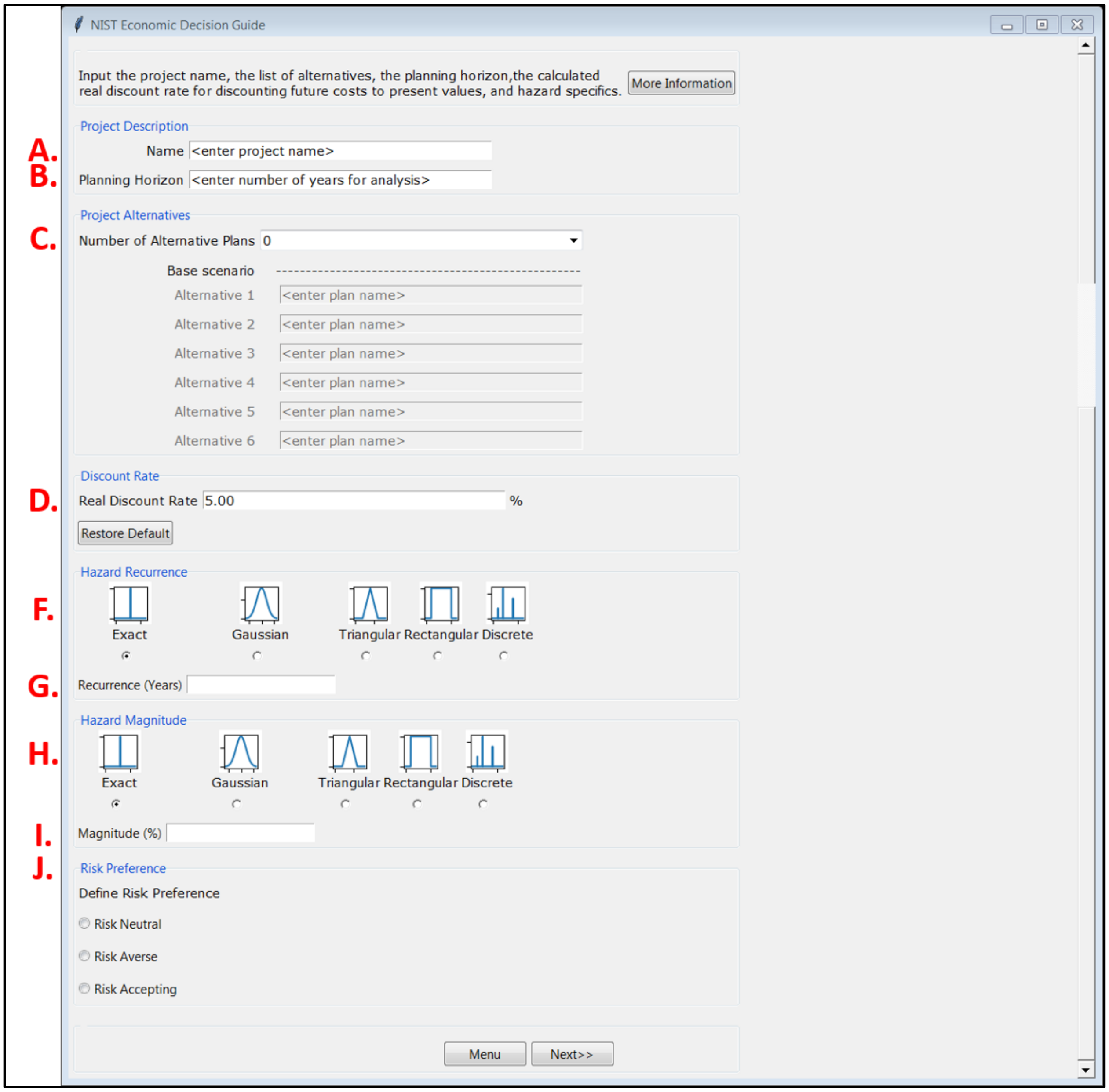


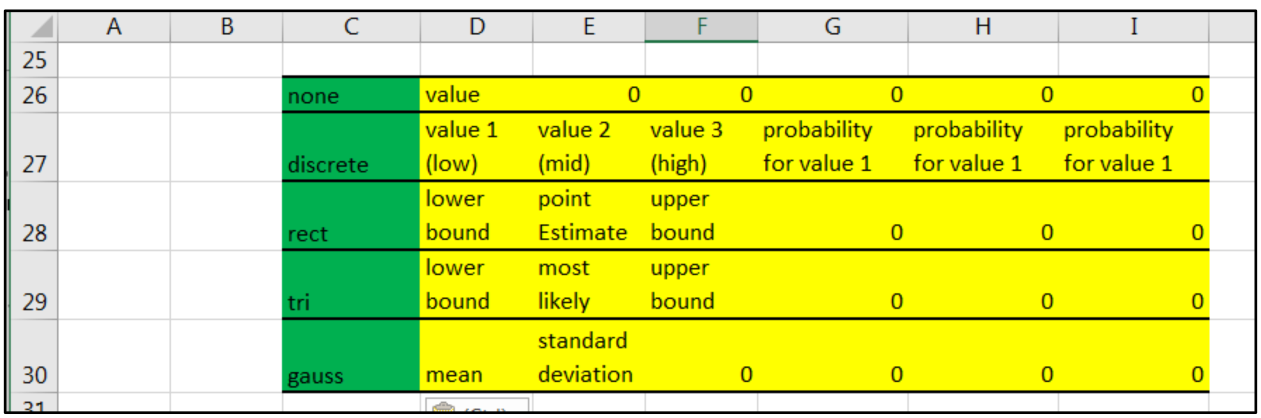
Figure C.2 *Project Information* page

Using Figure C.2, Table C.1 gives a mapping from the inputs found on the *Project Information* page to their location in the save file.

Table C.1 Project Information page mapping to Template tab

***Project Information* page input field**	**Input field letter from Figure C.2**	**Cell reference in Figure C.1**
Name	A	B1
Planning Horizon	B	E1
Number of Alternative Plans	C	--
Real Discount Rate	D	B2
Hazard Recurrence & Uncertainty	E	C4:I4
Hazard Magnitude & Uncertainty	F	J4:P4
Risk Preference	G	E2

Following Table C.1, you would put the project name in Cell B1, the planning horizon in Cell E1 and the real discount rate in Cell B2. The project name must not have any commas in it. The planning horizon must be zero or greater. The real discount rate is saved as a percentage, so the default 5 % would be saved as '5.' Risk preference is saved in Cell E2 and is not currently used in calculations, and so it is advised that you leave this field as is. If you wish to set the risk preference, no risk preference is 'none,' risk neutral is 'neutral,' risk averse is 'averse,' and risk accepting is 'accepting.' Hazard recurrence and its uncertainty is saved with each individual plan. In this version, through the GUI, it is assumed to be the same for every plan. The appropriate mapping here is pulled from the 'Add New Plan' tab of 'Template Construction v2,' seen in Figure C.3.



	A	B	C	D	E	F	G	H	I
25									
26			none	value	0	0	0	0	0
27			discrete	value 1 (low)	value 2 (mid)	value 3 (high)	probability for value 1	probability for value 1	probability for value 1
28			rect	lower bound	point Estimate	upper bound	0	0	0
29			tri	lower bound	most likely	upper bound	0	0	0
30			gauss	mean	standard deviation	0	0	0	0
31									

Figure C.3 Hazard recurrence and uncertainty template

The summary of what row to follow given a desired distribution, and what value the program chooses as the point estimate may be found in Table C.2.

Table C.2 Project Information page distribution mapping

Distribution Desired	Row from Figure C.3 to follow	Shortened Distribution name	Assumed point estimate cell
Exact (no uncertainty)	26	none	D26
Discrete	27	discrete	--*
Rectangular	28	rect	E28
Triangular	29	tri	E29
Gaussian	30	gauss	D30
* The assumed point estimate cell for the discrete distribution is input dependent			

For the discrete distribution, the assumed point estimate value is that of the maximum probability. If there are two maximum probabilities, it will take the first (e.g., if Value 1 and Value 3 are each 40 % likely, and value 2 is 20 % likely, the assumed point estimate value will be Value 1).

All hazard recurrence values must be greater than zero. The probabilities for the Discrete distribution are in percentages and must add up to 100%. The lower bounds for Rectangular and Triangular distributions must be below the point estimate values, which in turn must be below the upper bounds. If these don't follow, you will likely get unusual results. Furthermore, the standard deviation on the Gaussian distribution must be greater than zero else the program will fail.

Much like risk preference, hazard magnitude is an optional input and is not used for calculations in this version of EDGeS. It is advised that you leave these cells alone. If you wish to set hazard magnitude, it is saved in the same manner as hazard recurrence.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
4																
5	Plan 1	<Plan Name>	none	0	0	0	0	0	0	none		0	0	0	0	0
6		Fatalities	0	N/A												
7	END PLAN															

Figure C.4 New plan template

The number of alternative plans is not saved, but rather drawn from the number of plans listed. Each plan begins with the plan number, plan name, and the hazard recurrence and magnitude information, as seen in line 4 of Figure C.1 or line 5 of Figure C.4. It is then possible to define different hazard recurrences and associated uncertainties for individual plans from the save file where it is not from the GUI. While the calculations are completed, only the hazard recurrence for the Base plan is printed out in export files, and visiting the *Project Information* page will set the hazard recurrence for all plans to that of the Base plan.

Unlike in the GUI, the number of alternative plans is never directly stated, and is instead drawn from the number of plans contained within the save file. Each plan is concluded by a row consisting of only 'END PLAN' and the program is cued to the end of the file by the row consisting of 'END FILE' in the first cell. The plans are assumed to be in consecutive order, and so the first plan listed is always the Base plan, the next plan always Plan 1 and so on.

Each new plan must begin with Row 5 from the new plan template, found in the 'Add New Plan' tab of 'Template Construction v2,' where the plan number in Cell A5 is adjusted appropriately and end with a row consisting of only 'END PLAN' in the first cell. The first plan (Plan 0) is the Base plan, and has the plan name 'Base.' Each following plan name is defined in Cell B5 from Figure C.4, and these plan names must not have commas. Within a plan (i.e., after the 'Plan' line and before the 'END PLAN' line) the order of items does not matter. While save files created by EDGeS will always group inputs by type and go in a specific order, this is not necessary. Thus, a save file that is defined in the order of the first column of Table C.3 will be functionally identical to a save file with the order of the second column of Table C.3.

Table C.3 Two example orders of a save file

Benefit 1	Cost 1
Benefit 2	Cost 2
Benefit 3	Benefit 1
Cost 1	Cost 3
Cost 2	Benefit 2
Cost 3	Cost 4
Cost 4	Benefit 3

C.1 Set Fatalities Averted

Each project can only have one associated fatalities averted value. The line to define fatalities averted for a plan can be found in the New plan template (Figure C.4).

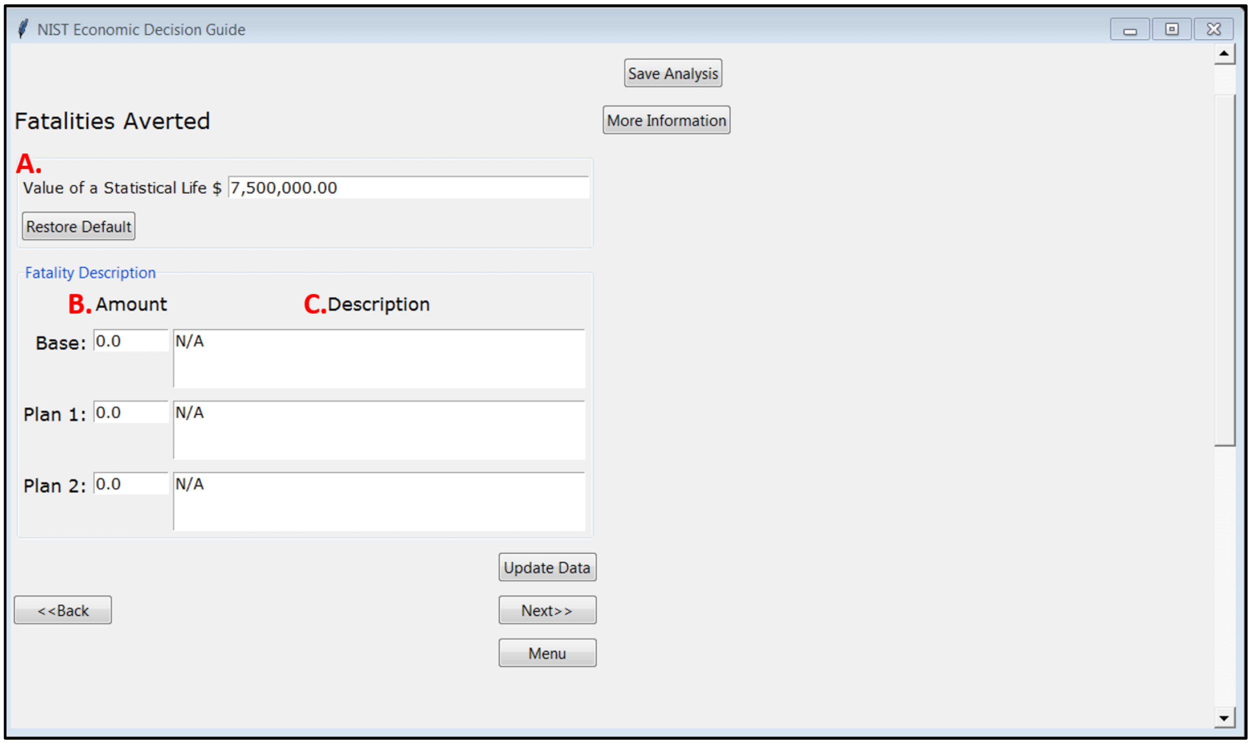


Figure C.5 Fatalities averted page

Table C.4 gives a mapping from the inputs in Figure C.5 to their location in the save file.

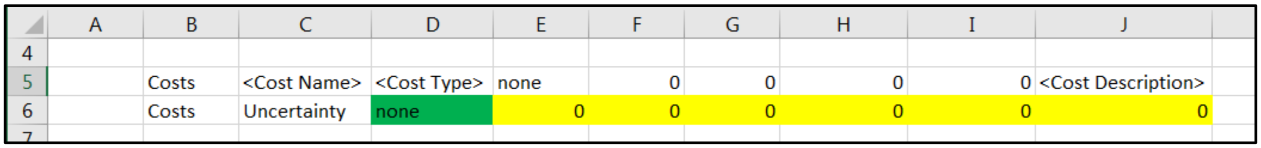
Table C.4 Fatalities Averted page mapping to template tab

***Fatalities Averted* page input field**	**Input field letter in Figure C.5**	**Cell reference**
Value of a statistical life	A	H2 in Figure C.1
Amount	B	C4 in Figure C.4
Description	C	D4 in Figure C.4

Note that the value of a statistical life is the same for all plans, and is found at the top of the save file along with the project name. In both the program and the template, this is given a default value of 7 500 000 USD, however you may set it to whatever value works best for you. Fatalities averted treats the aversion of injuries as partial fatalities averted. Since the save file is a .csv file, if the description field contains commas, upon reopening the file, this field will be parsed into several cells. This is known behavior and will not cause errors in EDGeS.

C.2 Define Costs

To add a cost, refer to the ‘Add new cost’ tab of ‘Template Construction v2,’ seen in Figure C.6.



	A	B	C	D	E	F	G	H	I	J
4										
5		Costs	<Cost Name>	<Cost Type>	none	0	0	0	0	<Cost Description>
6		Costs	Uncertainty	none	0	0	0	0	0	0

Figure C.6 Add new cost tab

Each cost is saved using two rows in the spreadsheet. The first row is for the cost information that would be found on the *Costs* page. The second row is for the associated uncertainties. Do not separate these two lines from one another, as the uncertainties may be applied to the wrong cost.

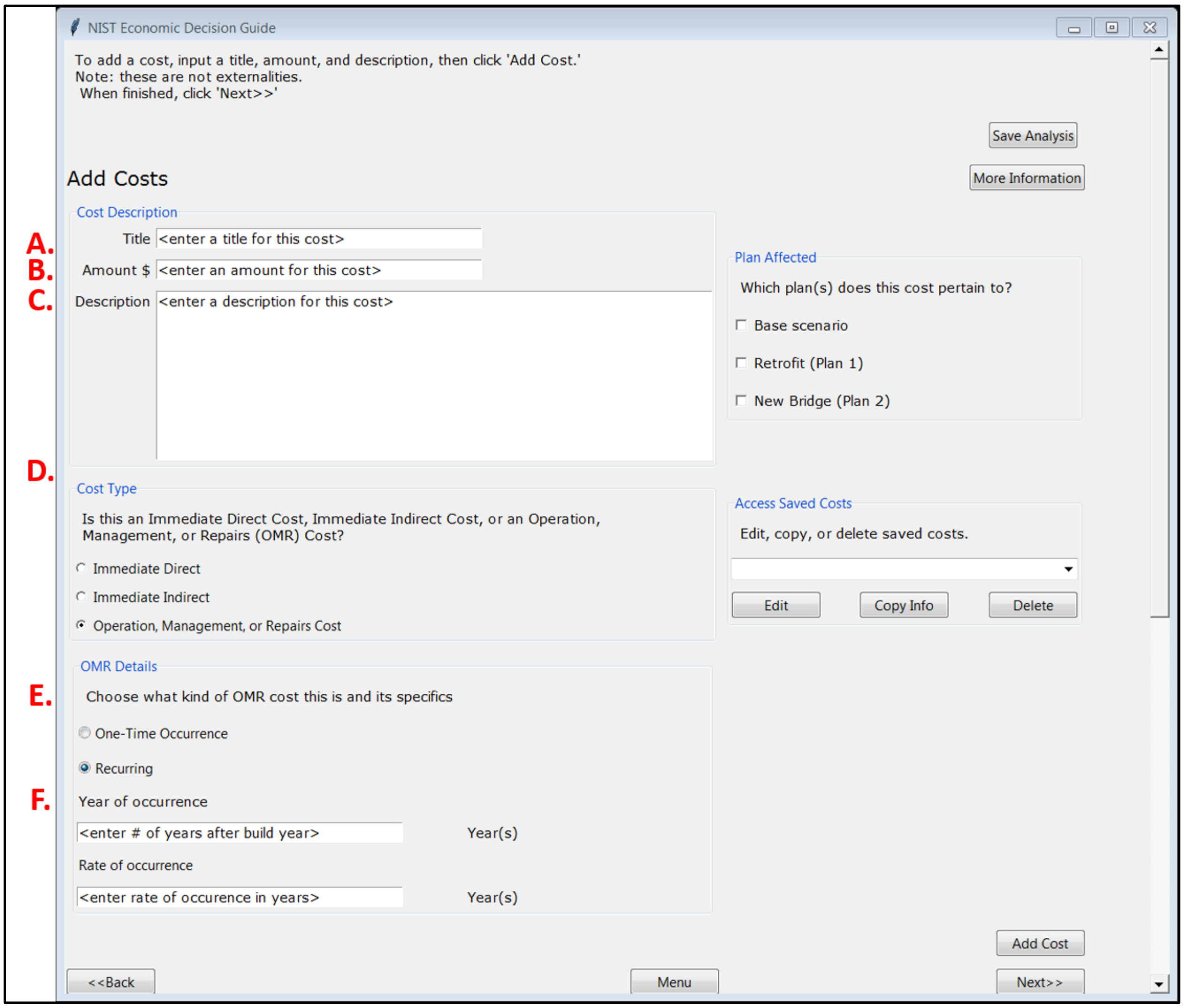


Figure C.7 Costs page

Table C.5 gives a mapping from the inputs in Figure C.7 to their location in the save file.

Table C.5 Costs page mapping to Add new cost tab

***Costs* page input field**	**Input field letter in Figure C.7**	**Cell reference in Figure C.6**
Title	A	I5
Amount	B	D5
Description	C	J5
Cost Type	D	D5
OMR Type	E	E5
Year of occurrence	F	F5
Rate of occurrence	G	G5

The cost title must not have any commas in it. In the GUI, the amount field is restricted to being zero or greater. Within the save file, negative costs are allowed and calculations will be done appropriately. Be aware that if you attempt to edit a negative cost in the GUI, it will not allow a negative amount. The options for the cost type (Cell D5) are ‘direct’ for an *Immediate Direct* cost, ‘indirect’ for and *Immediate Indirect cost*, and ‘OMR’ for an *Operation, Management, or Repairs cost*.

If the cost is not an OMR cost, the OMR Type should be ‘none’ and both years and rate of occurrence should be input as zeros. If it is an OMR cost, the OMR type may either be ‘one-time’ for *One-Time Occurrence*, or ‘recurring’ for *Recurring*. The *Year of occurrence* must be zero or greater. If the cost is recurring, the *Rate of occurrence* must be greater than zero. If this is set to zero for a recurring cost, this will create an infinite loop, causing the program to run until the computer runs out of memory eventually crashing the program. Cell H5 is for a feature not currently implemented, and may be left as a zero.

	A	B	C	D	E	F	G	H	I	J
38										
39				none	0	0	0	0	0	0
40				discrete	value 1 (low)	value 2 (mid)	value 3 (high)	probability for value 1	probability for value 1	probability for value 1
41				rect	lower bound	upper bound	0	0	0	0
42				tri	lower bound	upper bound	0	0	0	0
43				gauss	standard deviation	0	0	0	0	0
44										

Figure C.8 Uncertainties

The uncertainties for costs are similar to those for Hazard recurrence but there are some differences. Here, the point value has been collected on the previous line. To set Uncertainty (line 6 in Figure C.6) follow the appropriate line given the desired uncertainty from Figure C.8. For the triangular distribution, the point value is assumed to be the peak value, and for the Gaussian distribution, the point value is assumed to be the mean.

C.3 Define Externalities

To add an externality, refer to the ‘Add new externality’ tab of ‘Template Construction v2,’ seen in Figure C.9.

	A	B	C	D	E	F	G	H	I	J
4										
5		Externalities	<Externality Name>	none	0	0	0	0	<Externality Description>	
6		Externalities	positive	Community						
7		Externalities	Uncertainty	none	0	0	0	0	0	0

Figure C.9 Add new externality tab

Each externality is saved using three rows in the spreadsheet. The first two rows are for the externality information that would be found on the *Externalities* page. The third row is for the associated uncertainties. Do not separate these three lines from one another, as the externality may not be complete, or the uncertainty applied to the wrong externality.

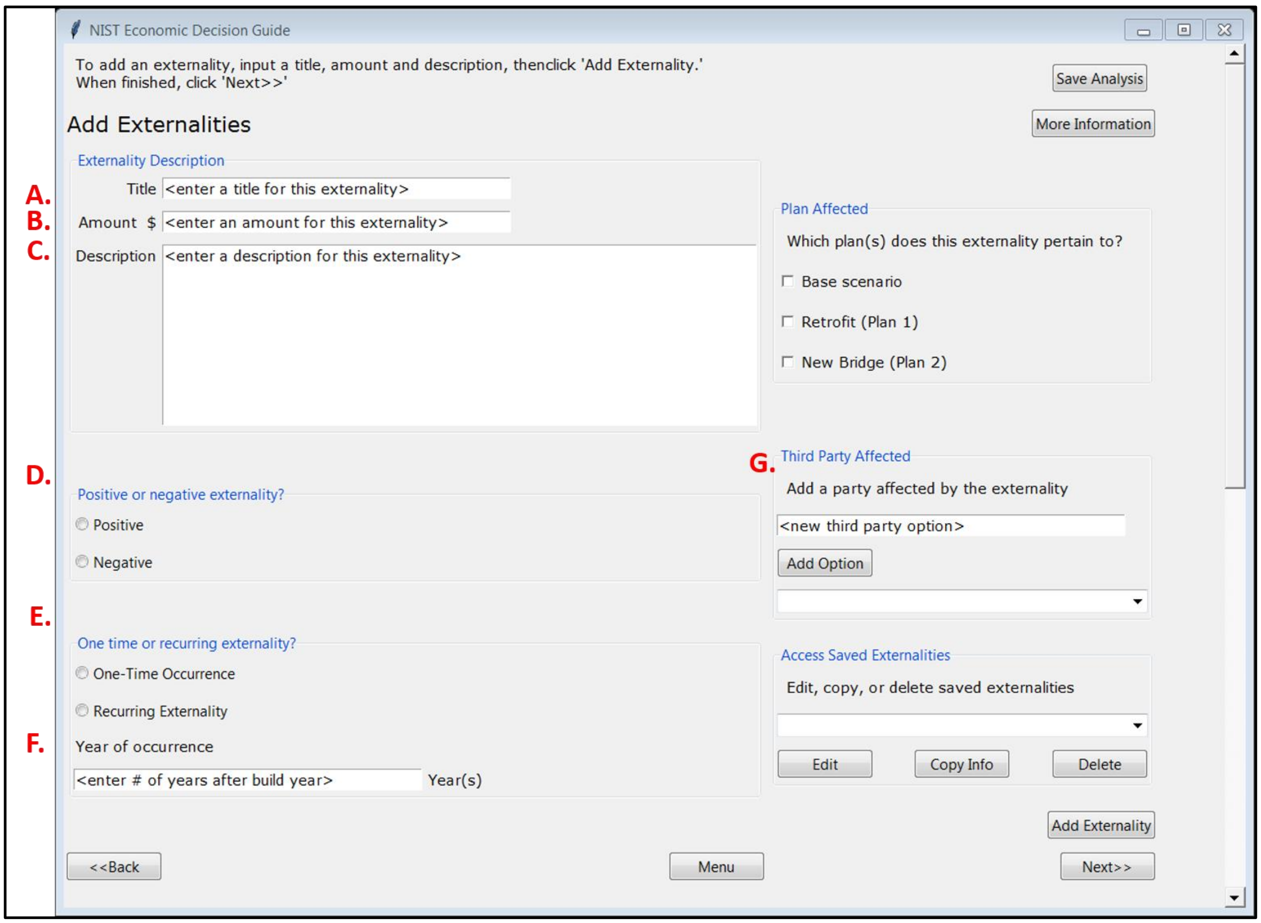


Figure C.10 Externalities page

Table C.6 gives a mapping from the inputs in Figure C.10 to their location in the save file.

Table C.6 Externalities page mapping to Add new externality tab

***Externalities* page input field**	**Input field letter in Figure C.10**	**Cell reference in Figure C.9**
Title	A	C5
Amount	B	H5
Description	C	I5
Positive or negative	D	C6
Recurrence	E	D5
Year & Rate	F	E5 (year), F5 (rate)
Third party affected	G	D6

The title must not have a comma. In the GUI, the amount field is restricted to being zero or greater. Within the save file, negative amounts for externalities are allowed and calculations will be done appropriately. Be aware that if you attempt to edit an externality with a negative amount in the GUI, it will not allow that negative amount. You should not need to use negative amounts, as the externality can be saved as positive or negative. The potential inputs for the *Recurrence* field (Cell D5) are ‘one-time’ and ‘recurring,’ the positive or negative cell refers to if this is a positive or a negative externality, where positive is denoted as ‘positive’ and negative is denoted as ‘negative.’ Like above, the year must be zero or grater, and the rate, if recurring, must be greater than zero. For the third party, the entry must only not include commas.

Uncertainties for externalities are saved the same as they are for costs.

C.4 Define Benefits

To add a benefit, refer to the ‘Add new benefit’ tab of ‘Template Construction v2,’ seen in Figure C.11.

	A	B	C	D	E	F	G	H	I	J
4										
5		Benefits	<Benefit Name>	direct	0	<Benefit Description>				
6		Benefits	Uncertainty	none	0	0	0	0	0	0

Figure C.11 Add new benefit tab

Each benefit is saved using two rows in the spreadsheet, the first for the benefit information that would be found on the *Benefits* page, and the second for the associated uncertainties. Do not separate these two lines from one another, as the uncertainty may be applied to the wrong benefit.

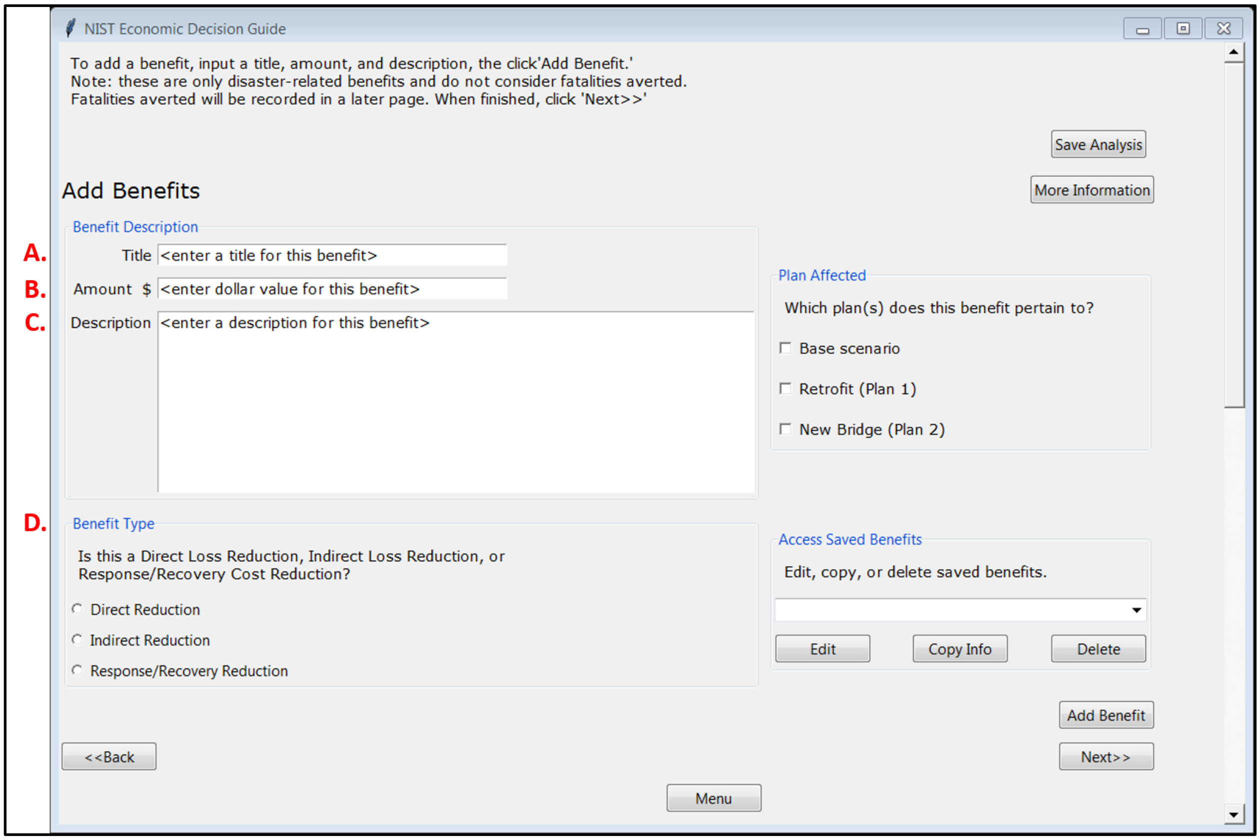


Figure C.12 Benefits page

Table C.7 gives a mapping from the inputs in Figure C.12 to their location in the save file.

Table C.7 Benefits page mapping to Add new benefit tab

***Benefits* page input field**	**Input field letter in Figure C.12**	**Cell reference in Figure C.11**
Title	A	C5
Amount	B	E5
Description	C	F5
Benefit Type	D	D5

The title may not have a comma. In the GUI, the amount field is restricted to being zero or greater. Within the save file, negative benefits are allowed and calculations will be done appropriately. Be aware that if you attempt to edit a negative benefit in the GUI, it will not allow a negative amount. The potential inputs for benefit type are ‘direct’ for *Direct Reduction*, ‘indirect’ for *Indirect Reduction* and ‘res-rec’ for *Response/Recovery Reduction*.

Uncertainties are done the same as for costs.

C.5 Define Non-Disaster Related Benefits

To add a non-disaster related benefit, refer to the ‘Add new NDRB’ tab of ‘Template Construction v2,’ seen in Figure C.13.

	A	B	C	D	E	F	G	H	I	J	K
4											
5		Non-Disaster Benefits	<NDRB Name>	none	0	0	0	0	<NDRB Description>		
6		Non-Disaster Benefits	Uncertainty	none	none	0	0	0	0	0	0

Figure C.13 Add new NDRB tab

Each non-disaster related benefit is saved using two rows in the spreadsheet. The first row is for the non-disaster related benefit information that would be found on the *Non-Disaster Related Benefits* page. The second row is for the associated uncertainties. Do not separate these two lines from one another, as the uncertainty may be applied to the wrong non-disaster related benefit.

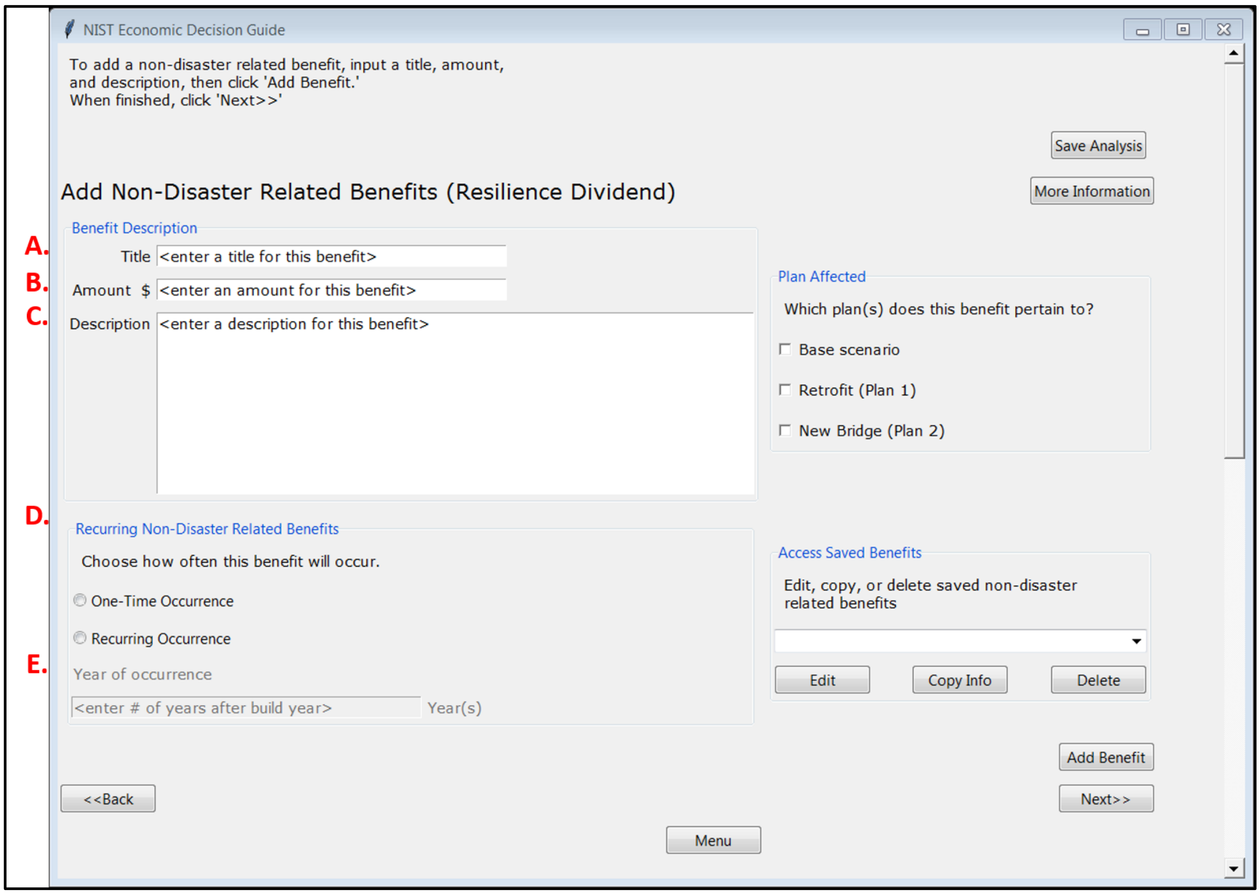


Figure C.14 Non-Disaster Related Benefits page

Table C.8 gives a mapping from the inputs in Figure C.14 to their location in the save file.

Table C.8 Non-Disaster Related Benefits page mapping to Add new NDRB tab

***NDRB* page input field**	**Input field letter in Figure C.14**	**Cell reference in Figure C.13**
Title	A	C5
Amount	B	H5
Description	C	I5
Benefit Type	D	D5
Year and Rate of occurrence	E	E5 (year), F5 (rate)

The title may not have a comma. In the GUI, the amount field is restricted to being zero or greater. Within the save file, negative non-disaster related benefits are allowed and calculations will be done appropriately. Be aware that if you attempt to edit a negative non-disaster related benefit in the GUI, it will not allow a negative amount. The benefit type is either 'one-time' for a *One-Time Occurrence*, or 'recurring' for a *Recurring Occurrence*. The *Year of occurrence* must be zero or greater, and if the benefit is recurring, the *Rate of occurrence* must be greater than zero. If this is set to zero for a recurring cost, this will create an infinite loop, causing the program to run until your computer runs out of memory eventually crashing the program. Cell H5 is for a feature not currently implemented, and may be left as a zero.

Uncertainties are done the same as for costs.

C.6 Save as Comma Separated Value (.csv) file

For the program to read in this file, it must be a .csv file. To save from Excel as a .csv, select *Save As* from Excel's *File* menu, select the desired location for the save file, and using the drop-down menu for selecting file type, choose *CSV (Comma delimited) (*.csv)*.

If this file is not properly formatted, the program may fail at initial read-in, in loading in or editing specific items from the GUI, or in running the analysis to completion. If an error occurs, the program will raise an error message, "The save file chosen is improperly formatted. Please choose a different file." In this event, you may manually inspect the input .csv against a file that is known to work.

Do note that Excel assumes .csv files have a rectangular structure, that is every line of the .csv file has the same number of entries. This can lead to extraneous commas being appended to the end of rows in input files, and thus on descriptions. This behavior does not have any impact on the numerical output but may be undesirable for the .docx export file. Extraneous commas may be removed manually using a text editor before analysis, or from output files.

If you have problems creating the save file from scratch, please use the GUI.

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