



Benefit Cost Analysis Guidance

A Framework For Conducting Benefit Cost Analysis
For Flood Risk Management Projects In Texas

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Acronyms

AIS	Abbreviated Injury Scale	EAD	Expected Annual Damages
AEP	Annual Exceedance Probability	FEMA	Federal Emergency Management Agency
AADT	average annual daily traffic	FPS	feet per second
BFE	Base Flood Elevation	FFE	First Floor Elevation
BCA	Benefit-Cost Analysis	FIF	Flood Infrastructure Fund
BCR	Benefit-Cost Ratio	FMA	Flood Mitigation Assistance
BEA	Bureau of Economic Analysis	FMP	Flood Mitigation Project
BLS	Bureau of Labor Statistics	FRM	Flood Risk Management
CDC	Centers for Disease Control and Prevention	F-SVI	flood-specific SVI
COAST	Coastal Adaptation to Sea Level Rise Tool	GSA	General Services Administration
CEQ	Council of Environmental Quality	GIS	Geographic Information System
DDF	Depth Damage Function	GI	Green Infrastructure
DV	depth x velocity	GDP	Gross Domestic Product
DEM	Digital Elevation Model	HMGP	Hazard Mitigation Grant Program
P&G	Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies	HCUP	Healthcare Cost and Utilization Project
EIA	Economic Impact Analysis	H&H	Hydraulics and Hydrology
ED	emergency department	IWR	Institute for Water Resources
ERDC	Engineer Research and Development Center	LCA	Life-Cycle Cost Analysis
EPA	Environmental Protection Agency	LWC	Low Water Crossings
		M&IE	Meals and Incidental Expenditures
		MHI	median household income

MEA	Millennium Ecosystem Assessment	SUV	sport utility vehicle
NASS	National Agricultural Statistics Service	SME	Subject Matter Experts
NED	National Economic Development	NRI	Texas A&M's Natural Resources Institute
NFIP	National Flood Insurance Program	TCEQ	Texas Commission on Environmental Quality
NOAA	National Oceanic and Atmospheric Administration	TDEM	Texas Division of Emergency Management
NSI	National Structure Inventory	TFR	Texas Flood Registry
NAVD88	North American Vertical Datum of 1988	GLO	Texas General Land Office
O&M	Operations and maintenance	TTI	Texas Transportation Institute
OMB	Office of Management and Budget	TWDB	Texas Water Development Board
PAR	Population-at-Risk	Dfund	Texas Water Development Fund
PLFZ	Potentially Lethal Flood Zone	TBL	Triple Bottom Line
PR&G	Principles, Requirements and Guidelines for Water and Land Related Resource Implementation Studies	USACE	U.S. Army Corps of Engineers
PE	Professional Engineer	USDA	U.S. Department of Agriculture
RI	Recurrence Interval	USDOT	U.S. Department of Transportation
RL	Repetitive Loss	UDV	unit-day-value
ROI	Return on Investment	DEFRA	United Kingdom's Department of Environment, Food, and Rural Affairs
RMC	Risk Management Center	VSL	Value of a Statistical Life
SLOSH	Sea, Lake, and Overland Surges from Hurricanes	VCM	Vegetative Cover Multiplier
SLR	Sea-Level Rise	VMT	Vehicle Miles Traveled
SRL	Severe Repetitive Loss	WRDA	Water Resources Development Act
SVI	Social Vulnerability Indices	HEC	Water Resources Hydrologic Engineering Center
SFHA	special flood hazard area	WSE	Water Surface Elevation
		WHO	World Health Organization

Glossary

Agglomeration: An economic theory that suggests that firms and households can enjoy positive benefit spillovers from the spatial concentration of economic activity

Annual Exceedance Probability: The probability of a flood event exceeding a predetermined elevation level during a one-year period

After Mitigation: The condition that will exist after the mitigation project is implemented

Baseline/No Action Alternative/Before Mitigation: The condition that will exist if a mitigation project is not implemented; Used to measure the benefits of implementing a project alternative

Benefit Cost Analysis: A comparison of project benefits with project costs using a defined methodology to convert benefits and costs to equivalent units

Benefit Cost Ratio: The ratio calculated by dividing the benefits of a project by the costs

Discount Rate: An interest rate used to discount future revenues or costs for a project; typically defined by the project sponsor before performing a benefit cost analysis

Diseconomies/Disbenefits: Negative impacts resulting from project implementation

Economic Impact Analysis: The impact of a project upon the regional or national economy as measured by income, employment, earnings, and taxes

First Floor Elevation: The elevation of the top of the lowest finished floor of a building

Flood Mitigation Project: A project designed to reduce the impact of flood events upon society

Fording Depth: The depth of water that a car can pass through without taking on water

Gray Infrastructure: Infrastructure that relies on non-natural features such as concrete to direct the flow of water

Green Infrastructure: Natural or semi-natural features that use plants or soil systems to capture, store, infiltrate, or evapotranspire stormwater

Hydraulics & Hydrology: Modeling used in engineering analyses to evaluate the movement of water, including the volume and rate of flow as it moves through a watershed, basin, channel, or man-made structure; hydrology refers to the rate of precipitation, the quantity of water, the rate of surface runoff, and the timing of its arrival at a point of interest, while hydraulics analyzes how surface and/or subsurface flows move from one point to the next

Independent Utility: Usable and complete even if no other improvements or phases are completed; a project has independent utility if it would be constructed absent the construction of other projects in the project area – portions of a multi-phase project that depend upon other phases of the project to achieve the desired results do not have independent utility

Lifecycle Cost Analysis: Total costs of a project over the expected project lifespan including maintenance and residual value

Net Present Value: The discounted value of future revenue or future costs which is based upon a defined discount rate and the future revenue/costs per year

Non-Structural Project: A project alternative that does not involve the construction of civil infrastructure; usually refers to acquisitions or elevations

Recurrence Interval: The average number of years between floods of a certain size

Repetitive Loss: An NFIP (National Flood Insurance Program) insured structure that has incurred flood-related damage for which two or more claims of more than \$1,000 were paid in any ten-year period

Return on Investment: A ratio that measures the profitability of an investment by comparing the gain or loss to its cost

Severe Repetitive Loss: An NFIP insured structure that has incurred flood-related damage for which four or more claims of more than \$5,000 were paid, or for which at least two separate claims payments have been made with the cumulative amount of such claims exceeding the market value of the building

Special Flood Hazard Area: Geographic area subject to a 1 percent or greater chance of flooding in any given year

Structural Project: A project alternative that involves construction, replacement, or repair of physical infrastructure such as levees or drainage systems

Texas State Flood Plan: A Statewide document that combines the findings of the 15 river-basin-based regional flood plans and makes legislative and floodplain management recommendations to guide state, regional, and local flood control policy; it sets forth specific, actionable evaluations, projects, and strategies that clearly demonstrate a path forward to reduce the risk and impact of existing flood risk and avoid the creation of future flood risks



1.0 Introduction

More than 75 percent of declared federal disasters in the United States are flood-related. Flooding is the costliest hazard in the United States,¹ causing greater loss of life and property than all other natural hazards (such as hurricanes, tornadoes, fires, and earthquakes) combined.² Following historic floods throughout the State of Texas in 2017, the Texas Legislature passed Senate Bill 8, which established the statutory framework for the Texas Water Development Board (TWDB) to institute flood mapping, planning, and funding programs for flood mitigation/prevention (also known as “Flood Risk Management” or FRM) projects across the state. In 2019, the Texas Legislature directed the creation of the first ever state flood plan for Texas, and the inaugural 2024 State Flood Plan was adopted on August 15, 2024. The State Flood Plan brings together the findings of the 15 river-basin-based Regional Flood Plans and makes legislative and floodplain management recommendations to guide state, regional, and local flood control

policy. The plan sets forth thousands of specific, actionable evaluations, projects, and strategies that clearly demonstrate a path forward to reduce the risk and impact of existing flood risk and avoid the creation of future flood risks.

Both planning and funding program requirements for FRM projects included in the Texas State Flood Plan, as well as for those that are seeking support from other funding programs, require the completion of a benefit-cost analysis (BCA) and a benefit-cost ratio (BCR) as part of their documentation. The BCA demonstrates the cost-effectiveness of a project, and the BCR is an outcome of the BCA that is calculated by dividing the total amount of a project’s benefits (expressed in dollars) by its total costs. When the ratio is equal to or greater than 1.0, that project is considered cost-effective.

BCR > 1
Cost Effective

BCR < 1
Not Cost Effective

Most federal flood grant programs also require a BCR as part of their application processes.

The Flood Control Act of 1936 was the first federal law that coordinated flood control measures across the nation.³ It instituted the federal use of BCA for evaluating the cost-effectiveness of potential FRM projects. In the century following that law, BCA has become one of the most widely used methods of determining the cost-effectiveness of FRM projects.

One of the benefits of requiring a BCA is that it charges project sponsors with justifying why a particular investment should be made; this justification must be borne from the careful consideration of an investment's impacts on its surrounding community, the state in which it will be implemented, and society as a whole. Carefully identifying a project's impacts is one of the most important steps in conducting a BCA. Describing project impacts helps frame the analysis and point sponsors toward the types of benefits that are most significant for a proposed project, allowing BCA efforts to be focused on those areas. It is important to consider all potential benefits at this point, regardless of whether they can be adequately quantified for inclusion in a numerical BCR. While the primary quantifiable benefit of an FRM project is often a reduction in flood damage to physical structures, they often result in a variety of other important benefits as well, including:

- » preventing losses of function for buildings, roads, utilities, and/or other infrastructure;
- » reducing injuries and loss of life;
- » providing environmental benefits;
- » reducing agricultural losses; and
- » improving water quality or quantity.

1.1 Document Purpose

This BCA Guidance Document will discuss how and why a BCA should be used to evaluate structural and non-structural FRM projects, limitations of conventional BCA methodologies, and how certain BCA limitations can be mitigated. The Document will also present values and methodologies that can be used to capture additional benefits within BCAs. While this document has primarily been developed to support TWDB flood planning and funding activities, it may be considered broadly applicable to FRM activities and project decision-making across other local, state, and federal agencies or partners.

This Guidance Document and the associated BCA calculation software tool (**TWDB Flood BCA Calculator**) attempt to balance the competing priorities of accuracy, transparency, reproducibility, and practicability while using sound economic theories of BCA that can be implemented by actual practitioners.

A BCA calculates the benefits expected to accrue from a project and compares them to the anticipated costs of the project over a specified period, which is typically the service life of the asset. The primary end result of a BCA is a BCR, which is a project's total benefits divided by its total costs. A project is considered to be "cost-effective" when the BCR is 1.0 or greater, indicating that the benefits of a project are sufficient to justify the costs. The BCR of a project will be contingent upon the type, cost, and comprehensiveness of the mitigation measure being considered; the number of people and structures that are being protected; and, importantly, the types of benefits that can be captured, measured, and monetized.

1.2 BCA Purpose and Methodology

BCA aims to promote efficient resource allocation through well-informed, transparent decision-making using quantitative analysis to the extent practicable. A BCA translates both monetary and non-monetary estimated project costs and benefits into dollar values, in order to incorporate disparate considerations into a unified accounting scheme. Initiating BCAs at an early stage can provide decision-makers with important data to support their decisions about resource allocation for further project development and implementation.

BCAs should include comprehensive estimates of the expected benefits and costs to society. Social benefits and costs can differ from private benefits and costs as measured in the marketplace because of imperfections arising from external economies or diseconomies where actions by one party impose benefits or costs on other groups that are not compensated in the marketplace, monopoly power that distorts the relationship between marginal costs and market prices, and taxes or subsidies⁴. Social net benefits, and not the benefits and costs to the agency funding the project, should be the basis for evaluating government programs or policies that have effects on private citizens or other levels of government.

“Benefits” can be broadly categorized as “economic,” “social,” or “environmental,” although there is often overlap between these categories. Sometimes a BCA includes benefits from all three categories, which is called a “Triple Bottom Line” (TBL) BCA.

While most FRM projects under consideration are anticipated to generate positive benefits, some projects may also result in negative benefits or benefit transfers. In such cases, those negative outcomes would be characterized as “disbenefits” and subtracted from the overall total of estimated benefits. An example of disbenefits would be a project that reduces flooding in one area but induces flooding in a neighboring area. BCAs should also distinguish between benefits and transfers: benefits reflect reductions in real resource usage and overall net benefits to society, while transfers represent changes in how those benefits and costs are distributed among various groups affected by the project. As such, transfers do not represent a net increase in societal benefits and thus are not legitimate additive benefits to be included in a BCA. An example would be an increase in property taxes due to increased property values that result from lower flood risk, which may be beneficial to local governments but represent costs paid by local property owners, with no net change in societal welfare.

The basic process for calculating the benefits of any project is as follows:

1. Define the baseline conditions in the study area;
2. Identify Project baseline damages/impacts;
3. Establish which impacts would be avoided and/or realized via implementation of the project; and then
4. Convert those impacts into economic/monetary benefits.

In studies with multiple alternatives, Steps 3 and 4 above would be repeated for each alternative for comparison. Beyond this approach, there is no strict formula or method for conducting a BCA, beyond incorporating costs and benefits into the analysis through “monetization” – that is, translating them into dollar values so that they may be added up over the lifetime of the project, discounted to a common year, and compared against one another. While this flexibility can be a benefit of BCA as compared with other types of economic analyses, it also means that BCA results depend fundamentally on discretionary factors embedded in the calculations, such as:

- » How and if non-monetary costs and benefits like environmental quality, health, injuries, lives, community, and quality of life are monetized and incorporated into the analysis;
- » Predictions of future conditions and project performance;
- » Estimated probabilities of future occurrences (such as disasters); and
- » How costs and benefits that accrue in the future are incorporated into the analysis, such as the length of the analysis period and the discount rate used to determine the net present value.⁵

Some such factors may be objectively based on expert technical evaluations, but others (such as how to value quality of life and community and natural assets) are inevitably subjective. Even comprehensive and well-documented BCAs can thus be heavily influenced by priorities embedded in the methodology.

Additionally, social benefits and costs can differ from private benefits and costs, as measured in the marketplace, because of imperfections arising from external economies or diseconomies. In such cases, actions by one party impose benefits or costs on other groups that are not compensated in the marketplace, driving a monopoly power that distorts the relationship between marginal costs and market prices, and taxes or subsidies. Social net benefits, and not the benefits

and costs to the agency funding the project, should thus be the basis for evaluating government programs or policies that have effects on private citizens or other levels of government.

In 2020, TWDB released an Excel-based **Flood BCA Calculator** to help project sponsors without prior BCA experience complete a BCA using standard values and approaches. More information about the Flood BCA Calculator is included in **Section 5.8 TWDB Flood BCA Calculator**. A key purpose of this Guidance Document is to present additional values and methodologies that expand upon prior versions of the Flood BCA Calculator to assist local sponsors in preparing a comprehensive BCA for their project(s). TWDB Flood BCA Calculator v2.0 is being released simultaneously with this Guidance Document to incorporate the findings described herein.





2.0 Basic Concepts in BCA

This section will explain several basic concepts that are important to understanding the BCA process: development of baselines, analysis periods, and inflation and discounting.

2.1 Baselines

Each BCA must include a well-defined baseline against which to measure the incremental benefits and costs of a proposed project. A baseline is sometimes referred to as the “no-build alternative,” “before mitigation,” or “without project condition.” The baseline defines the conditions that will exist without the proposed project and should include routine maintenance that would occur in the absence of the proposed project. If possible, a baseline should incorporate factors—such as population growth—that are not driven by the project itself and would occur even in its absence.

2.2 Analysis Period

The selection of an appropriate analysis period is a fundamental consideration of any BCA. By their nature, FRM infrastructure improvements typically involve large initial capital expenditures and resulting benefits continuing over many years. To capture this dynamic, the analysis period used in a BCA should thus cover both the initial development and construction of the project, and a subsequent operational period during which ongoing service benefits (and any recurring costs) are realized.

Analysis periods are typically set based on the expected useful service life of the improvement, which reflects the number of years until the same type of action (reconstruction, capacity expansion, etc.) would be anticipated to take place again. Projects with useful lives less than the analysis period should include recapitalization of the project at the

end of the useful life; projects with useful lives longer than the analysis period may include the residual value that remains at the end of the analysis period. Project sponsors should clearly describe the analysis period used in their BCA, including beginning and ending years, and explicitly state their rationale for choosing that period.

The analysis period should cover the full development and construction period of the project, plus an operating period after the completion of construction from which the full benefits and costs of the project can be reflected in the BCA. The appropriate analysis period will depend on both the type of improvement and its magnitude. For example, some types of smaller improvements (such as low-water-crossing signage) will have shorter useful lives than larger structural investments (such as bridges).

Analysis periods between 30 and 50 years are typical. Many Federal Emergency Management Agency (FEMA) projects use an analysis period of 30 years, but FEMA does allow local project sponsors to adjust their project's analysis period based on the project type, with appropriate documentation. Due to the large-scale nature of most of their projects, U.S. Army Corps of Engineers (USACE) projects frequently use an analysis period of 50 years.

There is a limit to the usefulness of modeling project benefits over very long analysis periods. General uncertainty about the future, specifically uncertainty about how population growth and development patterns may shift or evolve, means that predictions begin to lose reliability as the period of analysis gets longer. Additionally, in a BCA, each subsequent year is discounted more heavily than the previous year, and thus, each subsequent year is less likely to impact the overall findings of the analysis.

2.3 Inflation and Discounting

To ensure a meaningful comparison between benefits and costs, it is important that all monetized values used in a BCA be expressed in common terms. It is recommended that a common dollar year (such as the current year) be used to express all costs and benefits consistently so that proposed projects may be compared in the same terms. Such calculations require conversions from “nominal dollars,” which demonstrate something’s dollar value at the time it was generated, to “real dollars,” which demonstrate something’s dollar value adjusted for price level changes over time (i.e., inflation or deflation).

The federal Office of Management and Budget (OMB), a White House-level office that exercises broad administrative functions over the Executive Branch of the U.S. Federal Government, recommends in its [OMB Circular A-94](#) and [OMB Circular A-4](#) using the “Gross Domestic Product (GDP) Deflator” as a general method of converting nominal dollars into real dollars. The GDP Deflator is produced by the Bureau of Economic Analysis (BEA) and is a price index that captures changes in the value of a dollar over time by considering changes in the prices of all goods and services in the U.S. economy. The GDP Deflator measures price inflation or deflation and is calculated using “nominal dollar” GDP and “real dollar” GDP. The GDP Deflator provides numbers that can be used to multiply values in one dollar year to calculate the same real value in another dollar year.

After accounting for the effects of inflation or deflation to express costs and benefits in real dollars, a second, distinct adjustment must be made to account for the “time value” of money (i.e., its potential for earning interest). This is known as “discounting” and reflects the principle that benefits and costs that occur sooner in time are more highly valued than those that occur in the future. “Present value” is the concept that an amount of money today is worth more than that same amount in the future and takes into account any interest an investment might earn.

The federal discount rate (as provided by the U.S. Department of Treasury) is updated annually. The current Fiscal Year (FY) 2025 discount rate is 3.00 percent. However, for consistency, the OMB requires that all analyses submitted in support of legislative and budget programs, including those funded by FEMA, use a discount rate of 3.1 percent.⁶

Other types of economic analyses can include Life-Cycle Cost Analysis (LCA), Return on Investment (ROI), and Economic Impact Analysis (EIA).

LCA, for instance, calculates the total costs of the project over its useful life, but unlike BCA, does not consider project benefits.

ROI measures the gain or loss generated on an investment relative to the amount of money invested. Typically, ROI only considers the financial gains/losses to the entity making the investment and not the full impacts of the investment, which may include other economic, social, and environmental factors.

EIA measures the impact of increased economic activity within a specific area or region. While a BCA measures the value of a project's benefits and costs to society as a whole (typically on a national level), an EIA measures the impact of increased economic activity within a specific area or region, such as retail spending, business activity, tax revenues, jobs/wages, and property values. EIAs often take a strictly positive view (i.e., increased jobs, spending) and do not examine how the resources used for a project might have been put to alternative beneficial uses (i.e., by assessing the net effect on society). Positive impacts in one region may be accompanied by an offsetting of losses in a neighboring region, reflecting a transfer of spending or jobs that may be net neutral. Similarly, increases in jobs in one industry could reflect a decrease in jobs in a different industry. A project with negative net benefits could generate positive regional economic impacts simply by increasing spending or employment within a specific geographic area – even if, from a wider standpoint, is not cost-effective.

While these types of economic analyses have value when examining a decision for a particular stakeholder, they are distinct from BCA. In particular, when public funds are used for infrastructure investments, it is important to consider all broader economic, social, and environmental impacts when evaluating a project; LCA, ROI and EIA may not incorporate these considerations, while the BCA procedures described herein do.

3.0 Level of Analysis

For the purposes of the TWDB State Flood Plan and Flood Infrastructure Fund (FIF) programs, BCAs should be conducted for all individual flood mitigation projects (FMPs). TWDB defines an FMP as a proposed solution, both structural and nonstructural, that has a non-zero capital cost or other non-recurring cost, and that when implemented will reduce flood risk and/or mitigate flood hazards to life or property.⁷

Some FMPs can be assumed to be cost effective without going through the full BCA process; FEMA has developed “pre-calculated” benefits for such project types based on research and statistical analysis and/or computer modeling of mitigation projects.⁸ Additionally, certain emergency items or low-cost projects that are immediately effective in protecting life (such as early warning systems^{9,10}) may not need BCAs. BCAs are also usually not needed for studies being used identify problems and potential solutions. For further detail on when BCAs may be required by TWDB for certain proposed FRM projects, please refer to the latest **TWDB Flood Infrastructure Fund Intended Use Plan** documentation.

In addition, regulatory changes by government agencies may not need a BCA. While it is good practice to consider the benefits and costs of regulatory changes¹¹ (such as freeboard requirements¹² or fill prohibitions¹³ -- e.g. No Net Fill¹⁴ or No Rise Certification¹⁵), requirements for a formal BCA will vary by jurisdiction. Assessing BCA for regulatory changes is arguably more complex than performing BCA for a single project because one would need to estimate the anticipated impact of those flood-related regulatory changes over its jurisdictional area and over time. Also, some common flood-related regulatory requirements have already been studied extensively and shown to be cost effective.^{16, 17, 18}

Each BCA process starts with identifying the flooding problem and several possible solutions for resolving it (project conception). In the field of FRM, these solutions can involve non-structural (e.g., property acquisition or elevation) projects intended to reduce the consequences of flooding, or structural (i.e., infrastructure) projects intended to reduce water levels to lessen/eliminate floods themselves.

Structural projects can involve a wide array of different types of gray and green infrastructure (GI) depending on the problem that has been identified. If the identified problem involves flooding of residential or non-residential structures, non-structural projects should be considered as alternatives. At this time, TWDB does not explicitly require non-structural alternatives to be analyzed and presented alongside structural alternatives. Nevertheless, a good analysis will consider all alternatives. Federal agency rules vary, with some federal programs categorically requiring non-structural alternatives to be included in the array of possible solutions. All project alternatives (structural or non-structural, gray or green) are compared to a baseline (without project) condition, against which project benefits and costs are calculated.

Each alternative should have “independent utility,” meaning it can function on its own. **Sometimes large projects are phased to break the costs into manageable pieces that may be easier to fund; in order to conduct independent BCAs, each phase of these projects should be able to provide benefits regardless of whether subsequent phases are constructed.** If a particular phase of a project does not have independent utility, it is important to remember that that phase’s portion of the costs used for a BCA must match the portion used to calculate the benefits for the BCA, even if those costs are greater than the amount of funding that is being requested from a particular funding program.

Besides program requirements, which may specify the program used for a BCA and/or the level of detail required, there are two things to consider when determining the level of analysis that is appropriate for a BCA; the first is the level of design that has been completed for the project (such as Conceptual or Final Design) and the second is the total expected cost of the project.

3.1 Project Design

Depending on the complexity of an infrastructure project, its engineering and design will often go through several clearly marked stages of development (e.g., Conceptual or Preliminary, 30 percent, 60 percent, 90 percent, Final Design, etc.), with specificity and level of detail increasing at each stage. Since several outputs of the engineering analysis are inputs to the BCA, BCAs can also increase in specificity and confidence level as the design progresses. Although the calculations involved in estimating the benefits of a project remain the same (estimated damages in the baseline condition, minus estimated damages of an alternative), the level of specificity and subsequent confidence in the results should increase as the project advances from Conception to Final Design. Project costs are also often updated as the design progresses, which can be incorporated into BCA updates for a more accurate BCR result.

Two datasets are required to estimate flood damages to structures:

1. An inventory of all residential and non-residential structures that are expected to benefit from the project (which includes features such as location, number of stories, foundation type, structure value, and first floor elevation [FFE]), and
2. Hydraulics and hydrology (H&H) modeling (which includes water levels at each structure’s location before and after mitigation).

Both of these datasets may change as a project moves closer to Final Design and Construction, but in different ways.

The underlying number of structures benefiting from a project may not change much from project conception to construction, unless the project area boundaries change or the area is experiencing particularly fast growth. However, there are several data sources that can be used to compile a structure inventory, with varying levels of detail and accuracy.

For projects that are using the **TWDB Flood BCA Calculator** (See **Section 5.8 TWDB Flood BCA Calculator**), residential structures are classified as Small, Average, and Large, which reduces data gathering requirements; the analyst will need to determine the number of structures, location, and FFE of each structure within these three categories. This can be done with a simple desktop analysis via programs such as Google Maps or Google Earth to estimate FFE from ground level, and Lidar¹⁹ to estimate ground elevations if necessary. County or municipality assessor's offices are often another good data source for structure characteristics. In 2024, TWDB initiated a **Statewide Building Footprint Dataset Enhancement-Pilot** project to improve data standardization and quality of building structure information statewide. This effort is anticipated to evolve into a primary data source for public use.

If greater detail is needed, the analyst can compile a highly accurate structure inventory by hiring a surveyor to individually survey the number of stories, foundation type, and FFE of each structure within the project area. Structure values can be estimated using costs-per-square-foot by structure type and condition from paid services such as **RS Means** and the **National Building Cost Manual**. Real estate websites such as Zillow should be avoided because they do not separate out the value of the structure from the value of the underlying land.

Since benefit calculations are a function of flood levels before and after mitigation (i.e., Baseline and Project), benefits (avoided losses) will change anytime flood elevations change, which may or may not occur as project design progresses. Nevertheless, it is important to remember that the structure inventory may need to be updated to become more specific as a project moves from conception to Final Design, even if the H&H modeling has not changed, especially if simplifying assumptions were made in earlier phases.

3.2 Project Costs

A principal purpose of performing a BCA for public projects is to minimize the risk that the public agency will spend funds on a project that is not a good use of the public resources with which they have been trusted. This risk increases as the costs of a project increase and as the benefits of a project decrease. However, there is a tradeoff between developing the most accurate data to make the most accurate predictions about future conditions, and the costs associated with the time and resources required to do so. It is appropriate that more costly projects should spend more resources to ensure that the data used in their analyses is accurate.

Some FRM BCA models use default data to allow a wider range of applicants to conduct BCAs with less significant data requirements or specialized programs (such as the TWDB Flood BCA Calculator or the **FEMA BCA Toolkit**). These models are most appropriate for relatively low cost, low risk projects. Some models allow the analyst to choose the level of detail used (e.g., default data or user-input) but may require more specialized programs (e.g., Hazus, which requires the use of GIS). These models are appropriate for low-cost, low-risk projects where the analyst has the programs and experience necessary to run them but can also be appropriate for moderate-cost projects when using project-specific data.

The most complex FRM BCA models capture risk and uncertainty through distributions in the input data and the application of Monte Carlo simulations. These models are generally more complicated to run and usually require subject matter experts (SMEs) and extensive input data for as many as eight flood recurrence intervals (RI) in specific formats. These models are most appropriate for the largest, most expensive FRM projects.

More information about available BCA models can be found in **Section 5.0 Existing BCA Computer Models**.



4.0 Limitations of BCA Methods

Despite, or perhaps because of, the popularity of BCA as a decision-making tool, there remain several common criticisms of its calculation and application. The complete monetization of all benefit categories throughout a project's lifecycle is almost never possible, but even for those benefit categories with well-developed and accepted calculation methodologies, the process can be data-intensive and complex. Forecasts are inherently uncertain, "standard" values may or may not be appropriate for specific projects, and full probability distributions for the range of inputs are rarely available. Additionally, using monetized valuation as way to bring together and implicitly weight different effects into a single decision metric can mask important tradeoffs. It also does not necessarily address the distribution of benefits across different populations or other social objectives.²⁰

This section presents some common limitations of BCA and approaches on mitigating those limitations and developing reasonable BCAs. The usefulness of a BCA's results will depend on the accuracy of the input data, some of which may be difficult to obtain ([Section 4.1 Data Availability](#)). Due to the emphasis on monetization, projects that protect high-value properties may appear more worthy of investment than those with other types of impacts ([Section 4.2 Emphasis on Property Values](#)). Additionally, the results can be highly influenced by, and sensitive to, the discount rate that is used, which itself is inherently subjective ([Section 4.3 Sensitivity to Discount Rates](#)).

In 2020, TWDB released an Excel-based [Flood BCA Calculator](#) ([Section 5.8 TWDB Flood BCA Calculator](#)) to help project sponsors without prior BCA experience complete a BCA using standardized

values and approaches. A key purpose of this BCA Guidance Document is to expand upon TWDB's existing Flood BCA Calculator by providing additional values and methodologies that can assist local sponsors in preparing a comprehensive BCA for their project(s). This document and the **TWDB Flood BCA Calculator** attempt to minimize common limitations in the BCA process to the extent feasible. As stated in the Introduction, this Guidance Document and the TWDB Flood BCA Calculator attempt to balance the competing priorities of accuracy, transparency, reproducibility, and practicability while using sound economic theories of BCA that can be implemented by practitioners at the local level. Additionally, although BCA is an important part of the decision-making process, the TWDB project prioritization process includes many factors, of which BCA is only one.

In an ideal world, a comprehensive BCA should include all relevant impacts – physical, social, economic, and ecological. It should also analyze both direct impacts from the event, such as loss of life and damage to structures and infrastructure, as well as indirect losses, including any increased mortality or morbidity due to lack of sanitation facilities or unemployment and reduced income related to business interruption losses. But it is challenging to estimate how an event affects the value of goods that are not traded in the marketplace. These intangibles include the values of community cohesion, the value that a community places on its significant cultural or historical heritage sites, and the benefits derived from living in a beautiful place (for example, water views).

- Mechler, Reinhard, et.al. *Making Communities More Flood Resilient: The Role of Cost Benefit Analysis and Other Decision-Support Tools in Disaster Risk Reduction*. Zurich Flood Resilience Alliance. 9 September 2014. <https://pure.iiasa.ac.at/id/eprint/11193/>

4.1 Data Availability

Comprehensive and appropriate data is necessary for conducting a comprehensive BCA. This can often become a key constraint in conducting a proper, risk-based BCA that captures all project options. This can also become an equity concern, as smaller communities with fewer resources in particular may struggle to obtain this data. Examples of data requirements for the most widely used benefit categories are shown in Table 1. More information about each of these benefit categories is provided in **Section 6.0 Flood Risk Management (FRM) Project Benefits**.

Table 1: Examples of Data Requirements by Benefit Category

Benefit Categories	Examples of Data Requirements (For the Baseline and Project Alternative)
Flood Damages	Water elevations; number, type, value, and elevation of structures; debris totals
Loss of Function	Water elevations; number of households and businesses; impacted utilities
Life and Safety	Populations served and response times for emergency services; estimated injuries or deaths due to flooding
Environmental	Acres of habitat by type; reduction in stormwater runoff and treatment costs
Transportation	Traffic counts on streets that flood; detour routes
Agricultural	Land use and cropping patterns; acres of crops inundated; crop yields and expenses
Recreation	Number of recreational visitors; type of recreation; quality of experience
Water Supply	Annual or daily water supply yield; regional water costs
Residual	Construction costs; component lifespans

Two of the primary data needs for an FRM project's BCA are H&H data and a structure inventory. H&H modeling shows predicted water levels for various RIs throughout the study area, both with and without the project (i.e., Baseline and Project). H&H modeling is usually conducted by a licensed Professional Engineer (PE) using certified models/software and relevant data about the study area topography and drainage systems.

TWDB anticipates that Texas will be mapped and modeled with **Base Level Engineering** data throughout the state by late 2025. TWDB also maintains a **cursor flood data set** that includes statewide pluvial, fluvial, and coastal risks. The determination of which data set is best for a given area should be performed by a PE and/or in consultation with TWDB. TWDB has several **Financial Assistance Programs** related to flooding and the FIF can assist communities in developing H&H studies and analysis. Other flood related funding programs include: FEMA Flood Mitigation Assistance (FMA), FEMA Severe Repetitive Loss (SRL), and Texas Water Development Fund (DFund). **The Flood Information Clearinghouse** is a site that serves as a one-stop-shop for flood funding in Texas and is maintained collaboratively with TWDB, Texas General Land Office (GLO), and Texas Division of Emergency Management (TDEM).

To complete a structure inventory, basic structure data is often available from local assessor's offices; however, the data availability and usefulness will vary for each community. Additional effort may be needed to determine certain fields, such as FFEs.

The TWDB Flood BCA Calculator aims to minimize the complexity of conducting a BCA by decreasing the data collection and inputs required for project sponsors. This BCA Guidance Document furthers this goal by providing additional values and methodologies (primarily in the area of health and life safety) that can assist local sponsors in preparing a comprehensive BCA for their projects.

Data Management

Data management is of the utmost importance when conducting a BCA. Data management is the practice of collecting, keeping, and using data securely, efficiently, and cost-effectively. For the purposes of conducting a BCA, maintaining consistent units of measurement for each data variable across the BCA is essential; failure to do so can make BCA results meaningless.

For example, water elevation data and structure elevation data can both be reported in various datums, such as the North American Vertical Datum of 1988 (NAVD88), or in relation to the ground level. In some cases, water elevation data may be reported in relation to the FFE of each structure. Within the structure inventory, more than one residential or commercial unit may be in a structure (such as a duplex or a shopping center), and it is important to identify whether the associated square footage and value apply to an individual unit/address, or the entire structure. Either method is acceptable as long as the analyst consistently applies the correct structure value: the value for the entire structure if it is listed once, or the value for individual unit if each unit is listed separately. Similarly, some parcels have multiple structures (e.g., a residential structure with a detached garage or a commercial parcel with an industrial building and a separate office), and the analyst must take care to apply the correct square footage, value, and type to each appropriate structure. Examples of differing units that an analyst should be sure to verify may include, but are not limited to:

- » Number of residential/commercial units vs. number of structures
- » Datum²¹ (NAVD88 vs. NAD83)
- » Water surface elevations (WSEs) in absolute elevation vs. elevation above ground
- » Number of households vs. total population
- » Household income vs. per capita income
- » Elevation measurements in feet vs. meters

Incorporation of Risk and Uncertainty

Forecasts of future conditions, both for the Baseline and Project scenarios, by their very nature are uncertain. Even the most complex mathematical models cannot incorporate all of the factors that influence future economic and flood conditions, and experts can disagree about important choices that must be made in a BCA. Decision making in situations of profound uncertainty poses fundamental challenges. For example, picking a single representative projection can under- or over-estimate risk, while attempting to communicate results from multiple scenarios can be overwhelming.²²

There are various well-studied methods to incorporate uncertainty in BCA, such as using distribution functions and Monte Carlo simulations. However, these methods add complexity and additional data requirements to what can be an already-involved process, and frequently require data or information that is simply not available or not practicable to obtain. One way that the TWDB Flood BCA Calculator minimizes complexity is by not explicitly incorporating risk and uncertainty into the analysis. This is a trade-off that the TWDB acknowledges. **Therefore, for very large projects, the Flood BCA Calculator may not be the best BCA tool to use.** Additional tools, several of which explicitly incorporate risk and uncertainty through Monte Carlo simulations and other methods, are described in [Section 5.0 Existing BCA Computer Models](#). It is important to match the needs of the analysis (e.g., the type of data that is available or can be developed, whether risk and uncertainty need to be explicitly considered) with the appropriate BCA tool.





Case Study: FEMA New Orleans Oak Park HMGP Project (2018)

FEMA's Hazard Mitigation Grant Program (HMGP) provides federal funding for the prevention of future disaster-related damage. To receive funding, potential HMGP projects must have a BCA that demonstrates a 1.0 or greater BCR. FEMA-funded HMGP projects are required to use the FEMA BCA Toolkit; at the time the Oak Park project analysis was conducted, FEMA required a 7 percent discount rate.

In New Orleans, the Oak Park Project sought to invest in stormwater solutions such as stormwater lots and parks, pervious pavement, bioswales, rain gardens, retention basins, and underground storage. The City of New Orleans used this project to redevelop five vacant City-owned parcels into a stormwater management corridor utilizing underground stormwater retention tanks, which slowly release stormwater through a low dam (a "weir"). Benefits of the project included flood mitigation for 209 homes, new habitats for pollinators among the bioswales, and the avoidance of street flooding.

The BCA analysis for the Oak Park Project started with a building inventory, which included the address, square footage, and approximate elevation from the ground for all structures in the project area.

Google Maps was used to determine each structure's type, number of stories, and number of units; and to confirm all approximate elevations from the street. In some cases, FFEs were adjusted based on a visual comparison of the street and the structure. Building values per square foot were obtained from the 2017 National Building Cost Manual. The water elevations for the baseline and preferred alternatives were used to calculate flooding depths within the structures. Depth-damage functions were obtained from the BCA Toolkit V 5.3's Flood Module and varied based on the structure type.

Figure 1: New Orleans Gentilly Resilience District Projects²³



Even with the relatively modest scale of this project to reduce nuisance flooding at the neighborhood level, the BCA had to analyze over 200 individual structures. A custom

spreadsheet was developed to estimate the building and content damages and displacement costs for 2-, 5-, and 10-year storm events before and after mitigation. These damages were then input into the FEMA BCA Toolkit Damage Frequency Assessment module to calculate the BCR. The data that had to be collected for the BCA included:

- » FFE for each structure
- » Structure type/size for each structure
- » Baseline WSE for each structure for the following RIs
 - » 2-year storm
 - » 5-year storm
 - » 10-year storm
- » Project WSE for each structure for the following RIs
 - » 2-year storm
 - » 5-year storm
 - » 10-year storm

This demonstrates the level of data and applied expertise that is required to conduct a BCA for even a relatively small project using standard flood damage benefits, which are already expressed in dollar values.

4.2 Emphasis on Property Values

One of the most straightforward benefit categories to monetize for FRM projects is structural flood damage; therefore, this is the benefit type most often used in BCA. However, the dollar value of flood damage is highly dependent upon the value of the structure. This can lead to differences in BCAs for similar projects that protect areas with different property values. Even when the underlying value of the land is excluded (which it should be when calculating property damages), larger, more expensive homes and commercial structures will have more damage than more modest structures. As Headwaters Economics points out:

In practice, [BCAs] can undervalue the benefits of mitigation projects in lower-capacity and lower-income communities. This can result in the inequitable distribution of federal mitigation funds and perpetuate legacies of disinvestment in rural [and/or] under-resourced communities.²⁴

Overall, BCAs focused on property values can lead to wealthier communities being protected through mitigation and renovation projects, while less wealthy communities' cost-effective mitigation options become limited to "non-structural" alternatives, which may further confound efforts to safeguard the remaining structures via protective infrastructure, or are excluded altogether.

Several federal agencies that regularly conduct BCAs have recognized this concern. The 2014 publication, *Principles, Requirements, and Guidelines for Federal Investments in Water Resources (which replaces the 1983 Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies [the P&G])* states that,

Economic performance assessments ... largely focus on maximizing net economic development gains and typically involve an unduly narrow benefit-cost comparison of the monetized effects. Non-monetized and unquantified effects are often included in the overall analysis process but are not necessarily weighted

as heavily, or considered key drivers, in the final decision-making process. As a result, decision-making processes are, at this point in time, unnecessarily biased towards those economic effects that are generally more easily quantified and monetized. A narrow focus on monetized or monetizable effects is no longer reflective of our national needs ... [A] more integrated approach will allow decision makers to view a full range of effects of alternative actions and lead to more socially beneficial investments.

One goal of this BCA Guidance Document is to reduce the emphasis on property values by expanding the types of benefit categories that are considered and monetized so that the BCA process emphasizes people rather than property.

It is also important to note that, while a BCA is required for the Texas State Flood Planning process, it is only one factor considered when deciding which projects to study, fund, and construct.



Recent Changes to the USACE Decision-Making Process

Since 1983, the P&G have guided the evaluation and formulation of water resources projects proposed by the USACE and other federal water resources agencies. The 1983 P&G required agencies to undertake a broad analysis of all significant effects of any proposed federal water resources project and its alternatives and directed these agencies to recommend the alternative with the greatest net National Economic Development (NED) benefits, consistent with protecting the Nation's environment, unless the agency head granted an exception to this rule.

In 2007, Section 2031 of the Water Resources Development Act's (WRDA's) 2007 republication (Pub. L. 110-114) directed the Secretary of the Army to revise the P&G to address advancements in economic and analytic techniques; public safety; low-income community development; nonstructural solutions; and integrated, adaptive, and watershed approaches.

From 2009 to 2014, The Council of Environmental Quality (CEQ) led an interagency effort to modernize the P&G, after which the Water Resources Council re-issued it as the Principles, Requirements and Guidelines for Water and Land Related Resource Implementation Studies (the PR&G). The PR&G was designed to support water infrastructure projects with the greatest public benefits (defined as economic, environmental, and social benefits), avoid the unwise use of floodplains, and protect and restore natural ecosystems.

Some notable features of the PR&G include:

- » The concept of "public benefits," with a focus on striving to maximize economic, social, and environmental benefits relative to costs, with no hierarchy among them when evaluating alternatives for investments;
- » Facilitating choices for the recommended project so that the public benefits approach involves trade-offs among plans and outputs (economic, social, environmental), resulting in the decision maker having more projects than may be worthy of an investment;
- » Allowing professional judgment in determining which project is best, facilitated by appropriate consideration of trade-offs of monetized and non-monetized effects, resulting in an elevation of the role of qualitative data and the need for professional judgment in making recommendations;
- » Elevating ecosystem, sustainable economic development, floodplain, environmental justice, public safety and watershed considerations in terms of alternatives;
- » Offering differing levels of analysis, where the PR&G identifies the kinds of activities to analyze and provides for varying levels of detail;
- » Providing a means to certify equivalent processes as meeting the intent of the PR&G, where the full analysis is provided for major investments and scaled analyses are provided for smaller investments, streamlining the process and procedures to reflect the scope and complexity of the problem being assessed; and,
- » Recognizing limited fiscal resources more directly, potentially resulting in smaller projects that may not maximize the ROI, but allow for solving a water resources problem on a smaller or different scale.

An Army memorandum dated January 5, 2021, provided interim direction to the USACE to give equal consideration in its project studies to the economic, environmental, and social benefits of a proposed project and its alternatives.

Source: <https://www.regulations.gov/document/COE-2022-0006-0001>

4.3 Sensitivity to Discount Rates

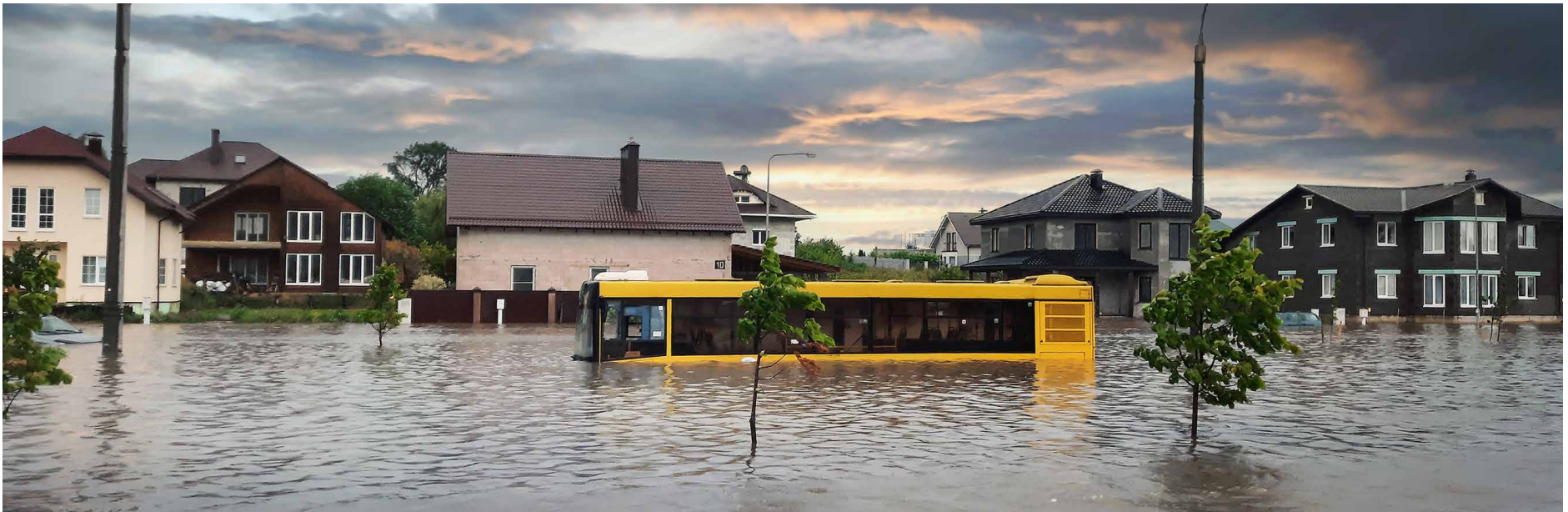
The discount rate is a key parameter in economic models that involve costs and benefits that accrue in the future. Benefits and costs that occur sooner in time are more highly valued than those that occur in the more distant future, as there is a cost associated with diverting resources for an investment from other productive uses in the future. This process, known as “discounting,” results in future streams of benefits and costs being expressed in present value terms. The higher the discount rate, the lower the present value of future benefits.

For typical projects with costs concentrated in early periods and benefits following in later periods, raising the discount rate tends to reduce the net present value. Therefore, high discount rates can prioritize low-cost, straightforward projects, or those that result in immediate benefits (such as emergency generators or the relocation of flood prone structures), over higher-cost, complex projects that have long useful lives and provide incremental benefits over an extended period (such as stormwater management systems). The

annual benefits provided by projects with large upfront costs that must be recouped over a long useful life diminish more rapidly under higher discount rates. The lower the discount rate, the greater the value of the estimated future benefits provided by the project.

Standard discount rates are set using subjective policy decisions that reflect competing social, economic, and political priorities. The OMB, for instance, recently decreased the discount rate required for all analyses submitted in support of legislative and budget programs, including those funded by FEMA, from 7 percent to 3.1 percent, the first change in over 20 years. FRM projects funded by the USACE and NRCS use discount rates that are updated and published annually in accordance with Section 80 of Public Law 93-251.²⁵ The discount rate for FY 2025 is 3.00 percent.²⁶

TWDB currently recommends use of the default discount rates in the [TWDB Flood BCA Calculator](#) and the [FEMA BCA Toolkit](#). As of March 2025, both programs use a default discount rate of 3.1%.





Case Study: Evaluating Flood Resilience Strategies for Coastal Megacities: Hurricane Sandy in New York City (2014)

Science magazine published the article “Evaluating Flood Resilience Strategies for Coastal Megacities” by Aerts, et.al, in May 2014.²⁷ This article presented a multidisciplinary, scientific approach to evaluating flood management strategies in the wake of Hurricane Sandy in NYC. Its methodology combined probabilistic risk assessment of storms with a vulnerability determination of exposed assets at the census tract level and was applied to three broad flood-mitigation strategies in NYC in the aftermath of Hurricane Sandy in 2012.

This analysis considered a broad range of storm scenarios alongside various discount rates and model outputs to create a comprehensive understanding of coastal flooding impacts on megacity environments. The three “classes” of flood mitigation strategies were the Resilient Open City (S1) strategy, which focused on enhancing building code regulations through elevation, as well as flood proofing of new and existing buildings; (S2), a strategy that would have created storm surge barriers; and a third strategy (S3) that represented a “hybrid solution” of the first two. The S2 strategy was further separated into three different specific storm surge barrier options: S2a, S2b, and S2c.

The study concluded that flood barriers and related structural measures would be effective at lowering the probability of flood hazard along the Northeast coast encompassing New York City, as well as protecting vulnerable coastal regions of the city. However, it also noted that such mitigations have a high cost of initial investment relative to other efforts, and thus possibilities like enacting stricter building codes for new and existing buildings would prove more cost-effective. This conclusion was tempered, however, with the warning that such efforts would not be as successful as flood barriers at protecting the city from flood waters.

The BCRs for the three different storm surge barrier systems (S2a, S2b, and S2c) for the middle climate change scenario ranged from 0.6 to 1.06 at a 7 percent discount rate, and 1.32 to 2.24 at a 4 percent discount rate (See Table 2). At the higher discount rate, only the least expensive structural option was cost-effective, but at the lower, all three options were cost-effective. This study demonstrated how large an effect a reduction in the discount rate could have on BCA outcomes; by reducing the discount rate from 7 percent to 4 percent the BCR was approximately doubled for all of the studied alternatives.

Table 2: BCRs at 4 percent and 7 percent discount rates for multiple flood management strategies in coastal New York / New Jersey

Climate Scenario	Discount Rate	Environ.dyn. S2a	Bay closed S2b	NY-JY connect S2c	Hybrid solution S3
Current Climate	4% discount	0.21 (0.11; 0.35)	0.21 (0.11; 0.34)	0.36 (0.11; 0.59)	0.45 (0.23; 0.73)
Current Climate	7% discount	0.13 (0.07; 0.21)	0.12 (0.07; 0.20)	0.23 (0.12; 0.37)	0.26 (0.13; 0.43)
Middle Climate Change Scenario	4% discount	1.32 (0.67; 2.16)	1.29 (0.65; 2.11)	2.24 (1.14; 3.67)	2.45 (1.24; 4.00)
Middle Climate Change Scenario	7% discount	0.60 (0.30; 0.98)	0.60 (0.30; 0.97)	1.06 (0.54; 1.74)	1.09 (0.55; 1.78)



5.0 Existing BCA Computer Models

Several federal agencies involved in flood protection have developed software programs to aid in determining the cost effectiveness of FRM projects. These programs include FEMA's **Hazus software** and **BCA Toolkit**, and the USACE's **HEC-FIA**, **HEC-FDA**, and **Beach-fx** programs. TWDB has also developed its own **Flood BCA Calculator**. Although TWDB encourages applicants to the State Flood Plan and FIF to use the Flood BCA Calculator, other available models are presented as recognition that there may be specific projects for which those programs may also be appropriate to use. The computer models listed here range significantly in complexity, but for all models, it is important that the user understands the assumptions that are made and whether those assumptions are appropriate for the project that is being analyzed. The programs are summarized in Table 5.

5.1 FEMA Hazus

FEMA's Hazus is a nationally-applicable, standardized methodology that contains models for estimating potential losses from earthquakes, floods, hurricanes, and tsunamis. Hazus uses geographic information systems (GIS) technology to estimate physical, economic, and social impacts of disasters using nationwide general GIS datasets.

The Hazus Flood model generates flood losses based on user-defined or Hazus-generated flood hazard data estimated from nationwide hydrological datasets. User-defined flood hazard data can be generated outside of the Hazus software and integrated into the flood model for greater accuracy at a particular site or region. This model estimates the expected levels of damage to infrastructure and buildings. Debris generation and shelter requirements can also be calculated.

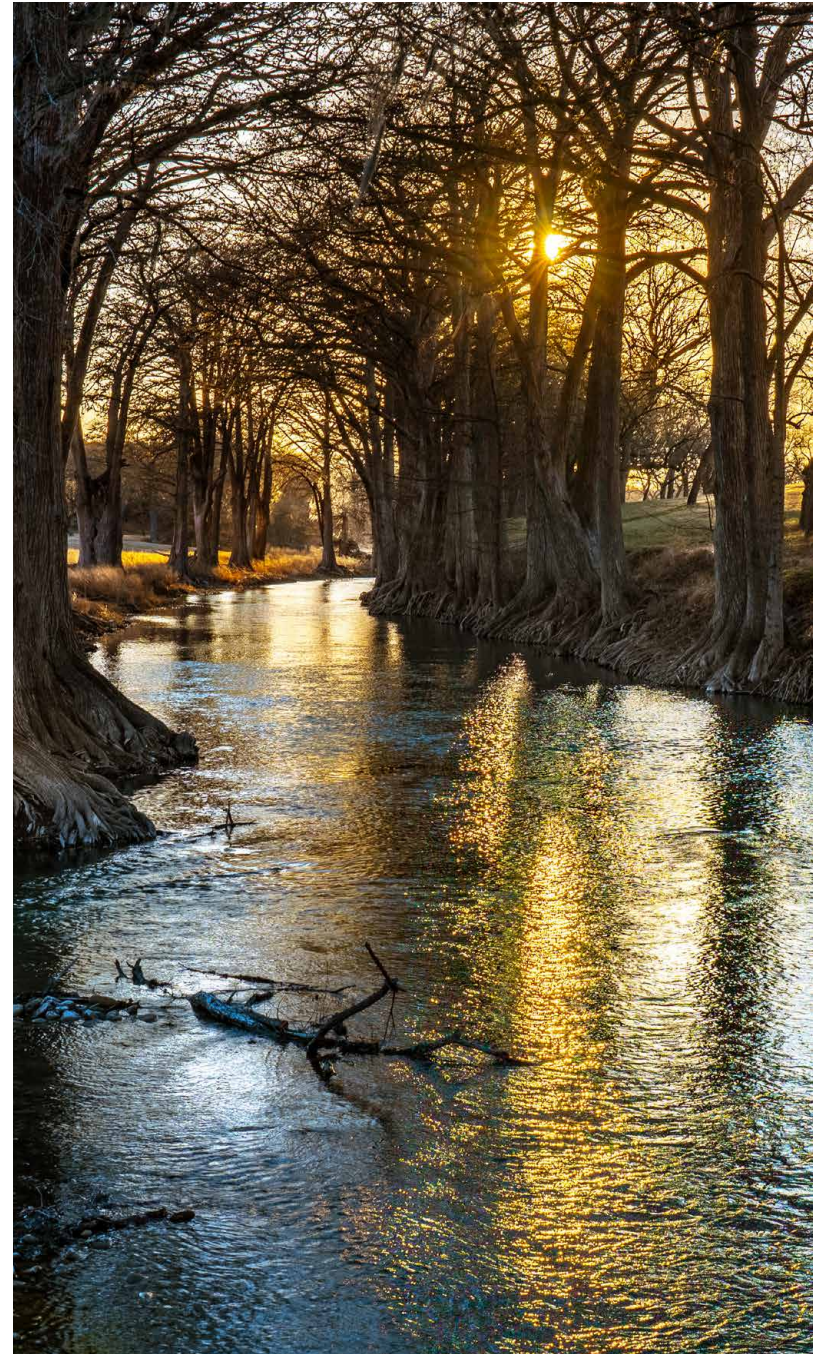
Hazus is packaged with General Building Stock (GBS) datasets that include building inventories and infrastructure for the entire United States. This software is currently built on GIS technology so that the inventory and infrastructure datasets can be mapped and intersected with the hazard information created from the disaster models. Then, Hazus can determine the water depths of buildings and infrastructure to calculate losses and damages. Losses estimated in Hazus are dependent upon the accuracy of input data. Building counts and square footages in the GBS are updated after every census (every 10 years).

Basic analyses (Level 1) can be developed using the default data and parameter data provided within Hazus. This provides baseline flood estimates based on existing 100- and 500- year flood levels. Users can also conduct more advanced analyses (Levels 2 and 3) using more accurate data that is specific to the region, hazard, or population. User-supplied data improves the accuracy of inventories and/or parameters; user-supplied flood levels would be necessary to estimate flooding in specific build alternative(s).

While a Level 1 analysis can reduce the data collection requirements with default and parameter data, the ability to use Hazus does require the knowledge of and access to GIS computer programs. More information about Hazus can be found in FEMA's 2021 document, [Using Hazus for Mitigation Planning](#).

Hazus FAST

The **Hazus Flood Assessment Structure Tool** (FAST) rapidly analyzes structure-specific flood losses using open-source Python rather than conducting the analysis within the Hazus software. Users now have the option to run an Average Annualized Loss analysis with the latest release of FAST. It calculates building-level flood impacts with user-provided building and flood depth data. FAST uses the standard Hazus Flood model methodology to assign Depth Damage Functions (DDFs) to buildings according to their occupancy type, FFE, foundation type, and number of stories. Flood depth is then extracted at every building and used as a DDF parameter to calculate flood losses in dollars. Flood-generated debris is estimated using building area in square feet. FAST is developed using the Hazus Python Package, HazPy, and requires Anaconda, which is a free software that automatically manages all Python packages required to run Hazus open-source tools.



5.2 FEMA BCA Toolkit

The **FEMA BCA Toolkit** software provides a suite of tools for analyzing each of the major natural hazards: earthquake, fire (including wildland/urban interface), flood (riverine, Coastal A Zone, Coastal V Zone), hurricane wind, and tornado. On July 23, 2019, FEMA released the BCA Toolkit Version 6.0, which may be used in the desktop version of Excel (Excel 2013 or later) or in Excel Online. Some major features of 6.0 include:

- » Excel-based platform
- » Compatible with both Windows and Macintosh operating systems
- » Streamlined user interface and improved user experience
- » Reduction in the number of manual-input data fields
- » Improved help content
- » Improved report formatting

The BCA Toolkit 6.0 includes three different analysis types that can be used depending on the type and detail of the data available. These are Modeled Damages, Historical Damages, and Professional Estimated Damages. The structure type options in 6.0 are Residential Structure, Non-Residential Structure, Critical Facility, Utilities, and Roads & Bridges.

For residential structures, non-residential structures, and critical facilities, the Modeled Damages approach is the default damage frequency approach. It analyzes proposed mitigation projects based on the effects that a range of storm events would have on buildings before and after the project is implemented. The Modeled Damages module is designed for evaluating individual buildings within a project and is recommended for BCAs where users have detailed flood hazard information and structural data for a project, including FFEs. This module's default DDFs apply to buildings, their contents, and their loss

of function and displacement times during and after a flood event. The Modeled Damages module provides a calculation of risk and benefits for mitigation projects.

In addition to the Modeled Damages approach, which requires individual structures to be input with FFEs, Base Flood Elevations (BFEs), and water heights and discharge levels at each RI, the BCA Toolkit also include “Historical Damages” and “Professional Estimated Damages” modules. For users familiar with older versions of the BCA Toolkit, these options replace the Damage Frequency Assessment module. These options are useful for calculating project benefits and costs for proposed mitigation projects when users do not have sufficient hazard or structural information for a more detailed analysis. These options allow the user to conduct analyses using either past damages with known event years (Historical Damages) or probable future damages with known RIs, as estimated by an H&H analysis (Professional Estimated Damages). In addition, these options allow for inclusion of other benefits calculated outside of the BCA Toolkit. The Historical Damages and Professional Expected Damages approaches are the only options available for Roads/Bridges and Utilities property types; the Modeled Damages approach is not available for a project that reduces damages for utilities or transportation infrastructure.

This tool is much easier to use than some of the other BCA options. However, it does not explicitly capture risk and uncertainty through methodologies such as Monte Carlo simulation or sensitivity analysis. The default discount rate for analyses conducted in the FEMA BCA Toolkit is 3.1 percent (as of March 2025). Users can edit the discount rate, but this is not recommended.

It is important to note that use of the FEMA BCA toolkit is a requirement of a number of FEMA grant applications, such as the HMGP, FMA, and BRIC Programs.



5.3 USACE Water Resources Hydrologic Engineering Center (HEC) Models

The USACE HEC specializes in the development, documentation, training, and application of hydrologic engineering and hydrologic models. HEC models that can be used to calculate economic benefits include Flood Damage Reduction Analysis (HEC-FDA) and Flood Impact Analysis (HEC-FIA). While the models are available on the HEC website, HEC does not provide support to non-USACE users.

HEC-FDA

The USACE developed its HEC-FDA software to perform integrated hydrologic engineering and economic analysis during the formulation and evaluation of flood damage reduction studies. The software 1) stores the hydrologic and economic data necessary for an analysis, 2) provides tools for visualizing data and results, 3) computes expected annual damages (EAD) and equivalent annual damages, 4) computes annual exceedance probability (AEP) and conditional non-exceedance probability, and 5) implements risk analysis procedures. The user inputs the discount rate that the model uses to calculate the EAD.

While the HEC-FDA model can estimate flood damages for large study areas and provide detailed results, it requires the input of large amounts of hydrological (e.g., flows, WSEs) and economic data. For example, HEC-FDA requires hydrologic data for eight RIs for each cross-section along the reach of a stream or river. In addition to these significant data requirements, the software is not as intuitive as other BCA options to use and can be difficult for community staff to learn and use effectively.

HEC-FIA

HEC-FIA software was developed by HEC in collaboration with the Risk Management Center (RMC) and Engineer Research and Development Center (ERDC). HEC-FIA evaluates property damage, agricultural loss, and loss of life from inundation events. Unlike HEC-FDA, HEC-FIA calculates the impacts of a single event and does not produce annual benefits or losses. HEC-FIA is typically used to perform dam and levee failure analyses to support consequence estimates and determine the risk posed or prevented by USACE projects. HEC-FIA is GIS-based and the results can be presented visually.

5.4 LifeSim

LifeSim was developed for the USACE RMC. This software estimates potential loss of life and direct economic damages from natural and dam/levee failure floods, as part of the USACE Dam and Levee Safety programs. It is an agent-based system that tracks individuals throughout the warning and evacuation process. During an evacuation simulation, agents interact with roads, vehicles, and the incoming hazard. After the warning and evacuation process has been simulated, LifeSim calculates lethality for those people who were exposed and direct damages due to the hazard.

By tracking individual people and their movements, LifeSim can help identify where people are most at risk of losing their lives, whether that is on roads or in structures. This can pinpoint the locations of greatest potential life loss, which is useful when developing alternative project formulations. LifeSim also applies both natural variability and knowledge uncertainty through Monte Carlo analysis. The results of such analysis provide a distribution of estimated consequences from a given hazard. Life loss and economic damages are then determined by the hazard (e.g. flooding). LifeSim does not produce annual benefits or losses.

Software developed at the RMC is made available to the public whenever appropriate. Use is not restricted and individuals outside of the USACE may use the program without charge. RMC will not provide user assistance or support for this software to non-USACE users but will respond to any reported software bugs.

5.5 Beach-fx

As part of its civil works mission, the USACE is responsible for the design, construction and maintenance of federally authorized shore protection projects. The ERDC's Coastal and Hydraulics Laboratory and the USACE Institute for Water Resources (IWR) created Beach-fx to model and measure the costs and benefits of protecting infrastructure against coastal erosion, inundation, and wave attack damages. The model consists of a Monte Carlo simulation that

evaluates beach erosion and other physical impacts that can occur from a storm coming ashore. Like HEC-FDA, the user inputs the discount rate that the model uses to calculate the EAD.

Like the HEC models, Beach-fx requires the input of large amounts of hydrological and economic data and is thus generally not recommended for public usage by non-economic and/or engineering professionals. The goal of this tool is to assist economists and engineers in coastal nourishment and rehabilitation studies.

5.6 Coastal Adaptation to Sea Level Rise Tool (COAST)

COAST software was developed at the University of Southern Maine with funds from the U.S. Environmental Protection Agency (EPA). The COAST model estimates flood depth at the parcel level and combines it with depth-damage functions to monetize risk. COAST uses data from the USACE's depth-damage functions, National Oceanic and Atmospheric Administration's (NOAA's) Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model and other flood methods, projected sea-level rise (SLR) scenarios over time, property values, and infrastructure costs to assess costs and benefits of different scenarios. It ultimately compiles these into a GIS-based picture of potential economic damage, including real property and building contents loss, lost infrastructure value, lost economic output, number of displaced persons, and affected natural resources. It can also be used for inland areas, as it can analyze and display the economic impacts of any potential hazard event that can be mapped (e.g., extreme rainfall, fire), as well as the social and environmental impacts of those events.

COAST bundles processes in Excel and the ArcGIS ArcGlobe application in the ArcGIS 3D Analyst extension.



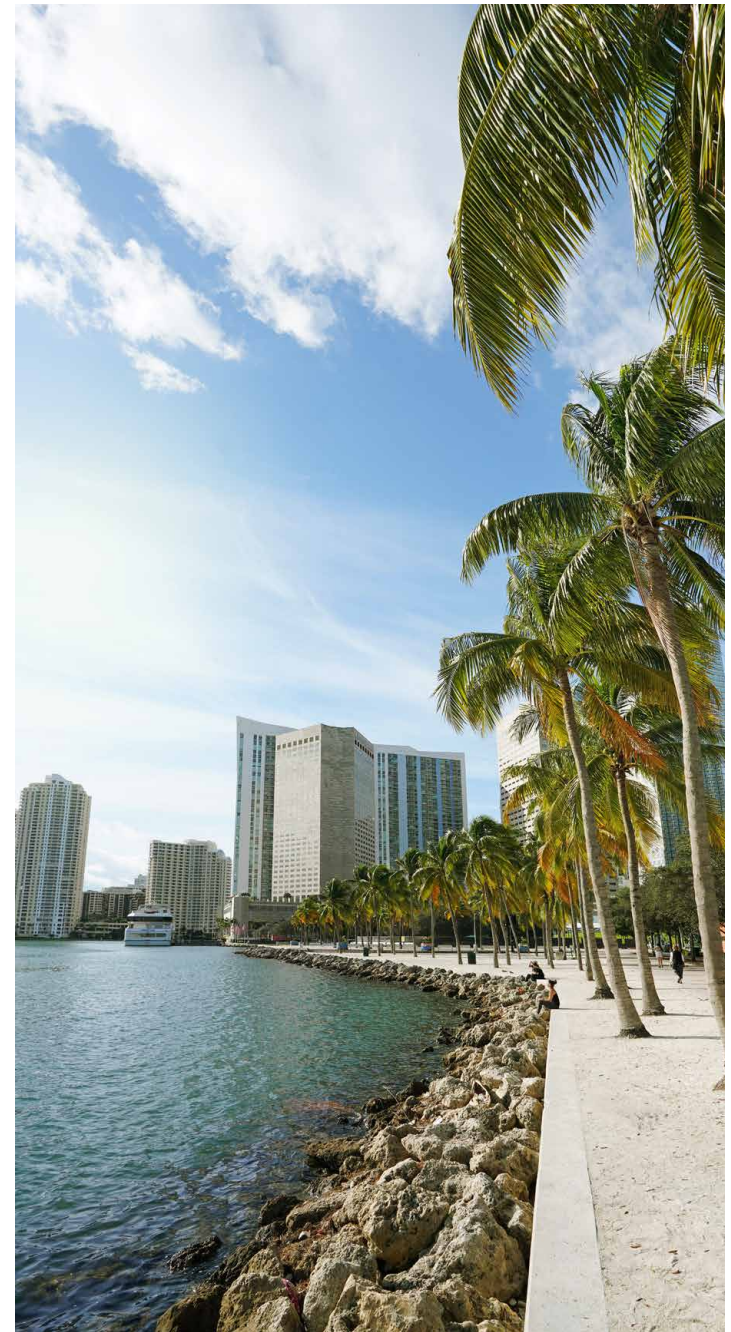
COAST Case Study: Downtown Miami Urban Redevelopment and Sea Wall Infrastructure (2019)

In 2019, the Miami Downtown Development Authority undertook a BCA for a project area spanning an 8.3-mile stretch of downtown Miami, which included 44,000 feet of shoreline, the city's historic center, museums, libraries, offices, schools, and many governmental offices. These analyses considered two alternatives to the status quo: a seven-foot sea wall alone, or a seven-foot sea wall augmented by a living shoreline comprised of red mangrove, salt meadow cordgrass, and rip rap.

The COAST model was selected for this analysis because H&H modeling was not available to provide flood depth inputs for economic loss estimations, and the COAST model does not require H&H data to generate risk results.²⁸ Instead, it used a Digital Elevation Model (DEM), land parcel boundaries, property values, and information regarding storm exceedance. The COAST model provided for the use of a built-in storm prediction model when H&H modeling data was not available.

The findings from the COAST model were further used to conduct a TBL analysis, which evaluated financial, social, and environmental costs and benefits. Financial impacts included capital expenditures, operations and maintenance (O&M) costs, replacement cost of structures, and residual value; social impacts included coastal and upland flood risk, property values, recreation values, urban heat island effects, education, and public health risks; and environmental impacts included contributions to water quality improvement, air pollution reduced by vegetation, and carbon sequestration of living shoreline.

The COAST model and TBL analysis predicted, based on the current shoreline condition, that 5.8 percent (274) of the 4,732 parcels in downtown Miami (8.1 percent of the city's total land) would be exposed to a 10-year storm event if one were to impact Miami in 2020. The model and analysis also predicted that the sea-wall-alone alternative had a TBL net present value of \$4,192,804, with a BCR of 9.2; while the sea-wall-with-living-shoreline alternative had a TBL net present value of \$4,654,639, and a BCR of 7.9.



5.7 Go Consequences

Go Consequences is an Economic Consequences Library written in Golang, an open-source programming language supported by Google. The Go Consequences library, available on GitHub, provides tools to support evaluating natural hazards interacting with consequence receptors. An example would be a flood represented by depth interacting with a residential structure to produce an estimate of economic losses at the residential structure. It uses the National Structure Inventory (NSI) (developed and maintained by the USACE), census data, crop data from **National Agricultural Statistics Service (NASS)**, standard USACE depth-damage functions for residential structures, and additional damage functions for commercial, industrial, and public structures (mostly sourced from Galveston).

5.8 TWDB Flood BCA Calculator

When the TWDB developed its Flood BCA Calculator (formerly known as the BCA Input Tool) in 2020, its explicit intent was to make developing a BCA easier for Texas municipalities applying for State Flood Plan consideration. Like the FEMA BCA Toolkit, **TWDB Flood BCA Calculator** Tool was developed as an Excel spreadsheet model that helps the user gather and organize necessary data, calculate impacts by RI, and annualize them over the project lifespan. It has the capacity to calculate benefits based on structural flood damages, loss of function for structures and transportation and utility infrastructure, agriculture damages, recreation, water supply, ecosystem services, and avoided morbidity and mortality. It also attempts to equalize property values by focusing on the number of residential structures impacted rather than the specific value of each structure and incorporating income weights (See **Section 7.0 Community Vulnerability**).

The TWDB Flood BCA Calculator does not explicitly incorporate uncertainties in the BCA inputs. However, given the excel-based nature of the tool, sensitivity or scenario analyses can be conducted by changing specific inputs in different instances of the model and reporting the range of resulting BCRs.

The TWDB Flood BCA Calculator and instructions for use can be found on the **TWDB website**.

Table 3: Benefit types included in FEMA BCA Toolkit (Modeled Damages) and TWDB Flood BCA Calculator

Benefit Types Included	FEMA BCA Toolkit v6.0 (as of March 2024)	TWDB Flood BCA Calculator v2.0
Structure Damages	✓	✓
Content Damages	✓	✓
Debris Cleanup Costs		✓
Flood Insurance Admin/Fees	✓	✓
Social Benefits (Mental Health & Productivity)	✓	✓
Flooded Vehicles		✓
Displacement Costs	✓	✓
Detours/Delays	✓	✓
Emergency Response Delays	✓	✓
Critical Facility Loss of Function	✓	
Utility Loss of Function	✓	✓
Transportation & Utility Infrastructure Damages		
Agricultural Damages		✓
Increased Water Supply Benefits		✓
Recreation Benefits		✓
Ecosystem Restoration	✓	✓
Green Infrastructure	✓	✓
Marginal Utility of the Dollar	✓	✓
Loss of Life (Low Water Crossings)		✓
Loss of Life (Flash Flooding)		✓
Health Impacts (Injuries & Disease)		✓

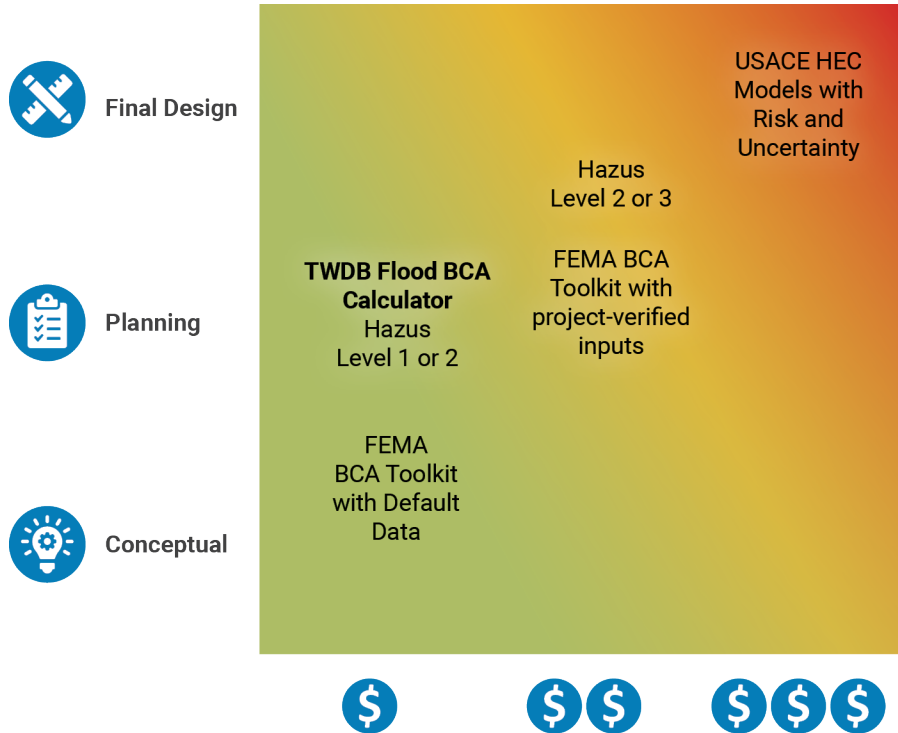
5.9 BCA Model Summary

As discussed in **Section 3.0 Level of Analysis**, the model used should be commensurate with the stage of design and the level of cost.

Figure 2 shows how the level of detail in a BCA should increase as the costs of a project increase.

It is also important to note that certain funding programs have specific requirements regarding BCA models. For example, FEMA grants require the use of the FEMA BCA Toolkit, although there is flexibility in how the input data for the BCA Toolkit is developed. USACE-funded projects require the use of USACE HEC models, which are usually operated by USACE economists or SME consultants.

Figure 2: Level of Analysis BCA Matrix



Some example purposes for an FRM BCA and its corresponding model are shown in Table 4.

Table 4: FRM BCA Purposes and corresponding models

Purpose	Model(s)
FEMA grant applications	FEMA BCA Toolkit
USACE-funded projects	USACE HEC Programs OR Beach- <i>fx</i> (for beach nourishment projects)
Floods related to dam/levee failures	LifeSim
TWDB State Flood Plan/FIF	Flood BCA Calculator
Internal planning purposes	Flood BCA Calculator OR FEMA BCA Toolkit OR FEMA Hazus Could be used in conjunction with COAST for coastal floodwater modeling

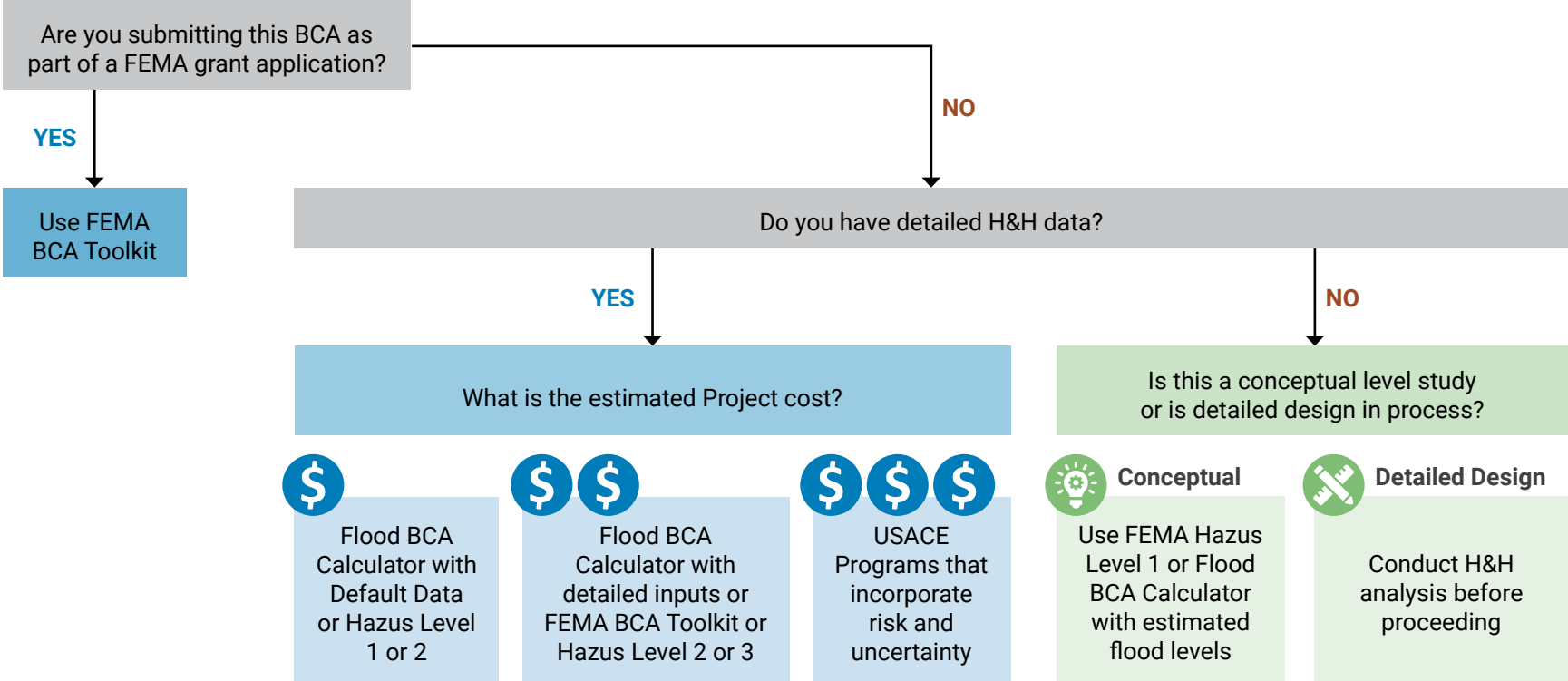
Pros and cons of some of the software options discussed are shown in Table 5. A flow chart that can help determine the appropriate model to use is shown as Figure 3.

Table 5: Pros and Cons of Existing Software

Software	Pros	Cons	Benefit Types Captured
FEMA Hazus	<ul style="list-style-type: none"> » Includes default data, including general building stock and water levels » Can be used for large regions as well as specific project sites 	<ul style="list-style-type: none"> » Requires the use of GIS » Default data may not be accurate at the parcel level » Assumes existing flood maps are accurate » Does not include all project benefit types 	<ul style="list-style-type: none"> » Flood Damage » Loss of Function » Agricultural
FEMA BCA Toolkit	<ul style="list-style-type: none"> » Excel-based, relatively simple to learn » Capable of including benefits calculated outside of the model » Can use historical damages 	<ul style="list-style-type: none"> » Does not include all project benefit types » Does not explicitly capture uncertainty in data inputs 	<ul style="list-style-type: none"> » Flood Damage » Loss of Function » Environmental » Social Benefits
HEC-FDA	<ul style="list-style-type: none"> » Very detailed and accurate results » Incorporates risk & uncertainty 	<ul style="list-style-type: none"> » Data-intensive » Difficult to master » Does not include all project benefit types 	<ul style="list-style-type: none"> » Flood Damage
HEC-FIA	<ul style="list-style-type: none"> » Very detailed and accurate results 	<ul style="list-style-type: none"> » Only measures one event; does not produce annualized results » Does not include all project benefit types 	<ul style="list-style-type: none"> » Flood Damage » Agricultural » Life & Safety
HEC-LifeSim	<ul style="list-style-type: none"> » Includes life loss benefits 	<ul style="list-style-type: none"> » Data-intensive » Difficult to master » Only applicable to events that include evacuation 	<ul style="list-style-type: none"> » Flood Damage » Life & Safety
Beach- <i>fx</i> (coastal flooding only)	<ul style="list-style-type: none"> » Very detailed and accurate results » Incorporates risk & uncertainty 	<ul style="list-style-type: none"> » Data-intensive » Difficult to master » Does not include all project benefit types 	<ul style="list-style-type: none"> » Flood Damage
COAST (coastal flooding only)	<ul style="list-style-type: none"> » Does not require H&H modeling for coastal analyses » Incorporates SLR projections 	<ul style="list-style-type: none"> » Depending on user skill set, expert level assistance may be required » Does not include all project benefit types » Some assumptions and methodologies are unclear 	<ul style="list-style-type: none"> » Flood Damage » Lost Economic Output » Environmental » Recreation » Public Health
TWDB Flood BCA Calculator	<ul style="list-style-type: none"> » Developed specifically for TWDB » Excel-based » Designed to minimize data requirements for users 	<ul style="list-style-type: none"> » Currently limited to 3 RIs » Does not explicitly capture uncertainty in data inputs 	<ul style="list-style-type: none"> » Flood Damage » Loss of Function » Life & Safety » Agricultural » Environmental » Recreation
Individually-Developed Code or Excel Workbooks	<ul style="list-style-type: none"> » Customizable » Can include benefits from all benefit types appropriate for the project » Can make other improvements as capabilities allow 	<ul style="list-style-type: none"> » Non-standard; harder to review and higher chance of calculation errors » May not be accepted by the grant program 	<ul style="list-style-type: none"> » Varies

FEMA uses the term “Social” benefits to capture mental health and anxiety costs and lost productivity avoided.

Figure 3: Flow Chart to Determine Appropriate BCA Model





6.0 Flood Risk Management Project Benefits

Benefits measure the economic value of outcomes that are reasonably expected to result from the implementation of a project. This section provides information about FRM project benefits and how they can be calculated. Note that the information presented here is compiled from multiple different data sources; therefore, dollar values are shown in differing dollar years. When completing a BCA, all benefits and costs should be inflated or deflated to a common dollar year. For more information about this process, see [Section 2.3 Inflation and Discounting](#).

Benefits can be broadly categorized as economic, social, and environmental, although there is often overlap between these categories. Some of the benefits that can be expected from FRM projects are listed in Table 6. These benefits should be considered representative rather than all-encompassing.

Many FRM benefits are difficult to quantify or monetize for inclusion in a BCA. The exclusion of any benefit types from this document does not imply that those benefits do not exist. In any BCA, all benefits relevant to a specific project should be explained qualitatively even if quantification is not practicable.

Table 6: Representative FRM Benefits by Benefit Category

Benefit Category	Representative Benefits of FRM Projects
Economic	Structural/ physical flood damages avoided
Economic	Non-residential displacement avoided
Economic	Emergency response costs avoided
Economic	Transportation and utility infrastructure damages avoided
Economic	Detour savings
Economic	Agricultural damages avoided
Economic	Residual value
Social/Economic	Residential displacement avoided
Social	Utility outages avoided
Social	Loss of emergency services avoided
Social	Fatalities and injuries avoided
Social/Economic	Mental health & productivity
Social	Recreational value
Social	Water supply value
Environmental	Ecosystem restoration
Environmental	Impact to threatened and endangered species
Environmental	Water quality
Environmental	Green infrastructure

There is often overlap between these categories.

6.1 Structure and content damages

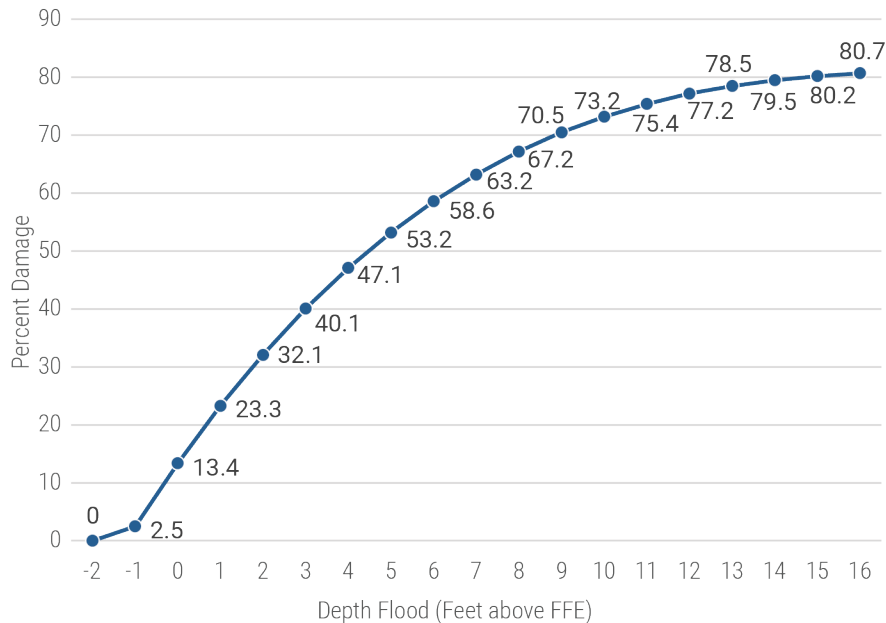
The primary benefit for FRM projects is usually flood damage reduction to physical properties. Benefits can include avoided damages to structures, contents, roads, and automobiles (or other large assets) and avoided costs associated with debris removal. Damages are generally estimated based on DDFs (see next section) and flood depths by RI for both Baseline and Project alternatives.

Depth-Damage Functions (DDFs)

FEMA and USACE have invested considerable research effort into developing DDFs that cover a wide variety of structure types. These DDFs estimate the damage to a structure based on the depth of flooding above first-floor as a percentage of the structure value. It should be noted that, at a certain point, the structure is considered a total loss; the [FEMA BCA Toolkit](#) default value for total loss is 50 percent damage. There are separate DDFs for the structure and the contents, as well as DDFs for length of displacement (in days). Figure 4 provides an example of a DDF that shows the percent of damage by flood depth in feet.

DDFs have been developed for the most common structure types of 1- and 2-story single family homes, apartments, and various types of commercial and industrial buildings. The use of a DDF to calculate damages requires several critical pieces of information, including basic data about a structure's purpose, foundation type, and value; and the depth of flooding in the structure.

Figure 4: Example DDF



Source: FEMA BCA Toolkit v6.0

H&H modeling (see [Section 4.1 Data](#)) should be conducted to estimate predicted water levels for various RIs throughout the study area for both Baseline and Project alternatives. H&H modeling is usually conducted by a licensed PE using certified models/ software and relevant data about the study area’s topography and drainage systems.

A structure inventory should be completed to identify all structures expected to be impacted by the proposed FRM project. Basic structure data is often available from a local assessor’s office; however, the data availability and usefulness of its format will vary for each project location. Each structure’s type and purpose are necessary to determine the correct DDF to apply (e.g., one-story residential without a basement, industrial, retail, etc.). This information may also be helpful in determining structure values.

Structure values can be estimated using the square footage of the structure and a value-per-square-foot. The values-per-square-foot of different types of buildings and their construction quality ratings can be found from paid services such as the [National Building Cost Manual](#) or [RS Means](#). The [Hazus Inventory Technical Manual](#) has structure replacement costs per square foot for over 40 occupancy codes and construction classes.²⁹ In the absence of other data, FEMA allows applicants to apply a generic value of \$100 per square foot to estimate structure values. It is important that the estimate of the structures’ values includes only the structures themselves (sometimes referred to as “improvements”) and **not the value of the underlying land**.

Additional effort may be needed to determine certain fields (such as FFEs) that are required to compare to H&H results to determine flood levels inside the structure. FFEs are often estimated using LiDAR data to estimate ground elevation, and by making assumptions regarding the height of a structure above ground based on the foundation type. For example, slab-on-grade structures can often be assumed to be 0.5 feet above ground level and mobile homes can often be assumed to be 2 feet above ground level.

Table 7: Height of a Structure above Ground by Foundation Type

Foundation Type	Height
Slab-on-grade Structures	0.5 feet
Mobile Homes	2 feet
Crawlspace	1.5 feet

Once all necessary data is collected, it is important to ensure that the analysis uses consistent units across data sources. WSE data and structure elevation data are reported in various datums, such as NAVD88, or in relation to the ground level. In some cases, WSE may be reported as flood depth in relation to the FFE of each structure. In many cases, more than one residential or commercial unit may be in a structure, and it is important to identify whether the associated square footage and value apply to the individual unit/address or the entire structure.

Structure and Content Damages Data Resources

There are multiple sources of information regarding DDFs from FEMA and the USACE. The USACE IWR report, [Catalog of Residential Depth-Damage Functions Used by the Army Corps of Engineers in Flood Damage Estimation](#), provides a discussion of DDFs and related topics. [Analysis of Non-Residential Content Value and Depth Damage Data for Flood Damage Reduction Studies](#) is another reference for this topic. Due to the availability of this data, DDFs for residential and non-residential structures will not be recreated here.

The USACE has also developed DDFs for vehicles, which can be found in [Economic Guidance Memorandum 09-04: Generic Depth-Damage Relationships for Vehicles](#). A summary of this DDF is included here as Table 8. The weighted average DDF is based on the distribution of vehicle types in the U.S.

Table 8: Percent Damage to Vehicles by Vehicle Type and Depth of Floodwaters above Ground

Depth above Ground	Sedans	Pickups	SUVs	Sports	Minivans	Weighted Average
6"	7.6%	5.2%	0.0%	1.4%	0.0%	2.2%
12"	28.0%	20.3%	13.8%	29.2%	17.8%	18.3%
18"	37.1%	27.4%	22.2%	64.6%	28.1%	28.5%
24"	46.2%	34.4%	30.6%	100.0%	38.3%	38.6%
36"	100.0%	47.5%	45.8%	100.0%	100.0%	59.6%

Source: USACE EGM 09-04³⁰

Since vehicles can potentially be moved out of the way of floodwaters, it is also important to consider the number of people who will move their vehicles based on the amount of warning time they have available; this is shown in Table 9.

Table 9: Percentage of Population Moving at Least One Vehicle to Higher Ground

Warning of 6 hours or less	Warning of 6 hours or less	Warning between 6 and 12 hours	Warning between 6 and 12 hours	Warning greater than 12 hours	Warning greater than 12 hours
Percent moving vehicles to higher ground	Percent not moving vehicles	Percent moving vehicles to higher ground	Percent not moving vehicles	Percent moving vehicles to higher ground	Percent not moving vehicles
50.5%	49.5%	80.6%	19.4%	88.1%	11.9%

Source: USACE EGM 09-04

DDFs for various structure types are also embedded in FEMA's Hazus and BCA Toolkit v6.0.

In addition to the fluvial and coastal USACE and FEMA-developed DDFs, pluvial-specific DDFs were developed by Porter, et.al (2023)³¹ for metropolitan and non-metropolitan areas, and are available in the [America Society of Civil Engineers Natural Hazards Review Volume 24, Issue 1](#).

The [TWDB Flood BCA Calculator](#) uses estimates of damage by depth of flooding for Small, Average, and Large homes to simplify data collection requirements. These are based on the USACE Generic Depth Damage Function and values per square foot of \$100 (FEMA Default value) for all homes. Damage estimates for an “Average” home are shown in Table 10.

Table 10: Damages to Structure and Contents of an Average Home by Interior Water Depth

Interior Water Depth (Inches)	Cost to Home	Cost to Personal Property	Combined Potential Loss
1"	\$36,000	\$21,000	\$57,000
2"	\$38,000	\$22,000	\$60,000
3"	\$40,000	\$23,000	\$63,000
4"	\$42,000	\$25,000	\$66,000
5"	\$44,000	\$26,000	\$69,000
6"	\$46,000	\$27,000	\$73,000
12"	\$58,000	\$33,000	\$92,000
24"	\$80,000	\$44,000	\$125,000
36"	\$100,000	\$55,000	\$155,000
48"	\$118,000	\$64,000	\$182,000

Average Home = 2,500 square feet

The cost of physical damages can be calculated using the following equation:

Figure 5: Flood Physical Damages Equation

$$\begin{aligned} & \text{Structure and Content Damages} \\ &= \sum_{\text{Structure}} (\text{Percent structure damage} * \text{Structure value}) \\ &+ \sum_{\text{Structure}} (\text{Percent content damage} * \text{Contents value}) \end{aligned}$$

...where the percent damage is obtained from the DDF for each type of structure being evaluated and the depth of flooding as compared to the FFE.

Separate damage estimates should be calculated for each modeled RI for both the Baseline and Project alternatives. The total damages by RI are annualized and compared between the Baseline and Project alternatives to calculated project benefits. The annualization process is described in [Section 6.12 Discounting and Annualization](#).



Debris Removal

Flood damage can produce a significant amount of debris that requires cleanup and disposal. Debris removal and cleanup includes the collection, processing, and disposal of debris. These activities vary depending on debris material types and land use types.

Debris cleanup is an important action that has both short-term and long-term considerations. In the short term, removal of debris is necessary to facilitate the recovery of a region; in the long term, disposal methods of debris must be considered so that its management does not pose a future threat to human health or the environment (e.g., hazardous waste). The reduction or elimination of the costs associated with cleanup and disposal can be included as a project benefit.

FEMA Publication 329, the **Public Assistance Debris Estimating Field Guide**, can be used to estimate flood debris volumes in cubic yards for various residential structure types and sizes. The general building formula is:

Figure 6: Debris Estimate Equation

$$\text{Cubic Yards of Debris} = \frac{\text{Length (ft)} * \text{Width (ft)} * \text{Height (ft)} * 0.33}{27}$$

The resulting cubic yards of debris can be multiplied by a Vegetative Cover Multiplier (VCM) to account for vegetative debris, as follows:

- » Light (1.1 multiplier) includes new home developments where more ground is visible than trees and canopy cover is sparse.
- » Medium (1.3 multiplier) generally has a uniform pattern of open space and tree canopy cover and is the most common description for vegetative cover.
- » Heavy (1.5 multiplier) is found in mature neighborhoods and woodlots where the ground or houses cannot be seen due to the tree canopy cover.

The cubic yards of debris produced by a typical 1-story single family residence, by square footage, is shown in Table 11.

Table 11: Cubic Yards of Debris Produced by a 1-story, Single Family Residence

Typical House (Square Feet)	None	Light (1.1)	Medium (1.3)	Heavy (1.5)
1,000 SF	200 CY	220 CY	260 CY	300 CY
1,200 SF	240 CY	264 CY	312 CY	360 CY
1,400 SF	280 CY	308 CY	364 CY	420 CY
1,600 SF	320 CY	352 CY	416 CY	480 CY
1,800 SF	360 CY	396 CY	468 CY	540 CY
2,000 SF	400 CY	440 CY	520 CY	600 CY
2,200 SF	440 CY	484 CY	572 CY	660 CY
2,400 SF	480 CY	528 CY	624 CY	720 CY
2,600 SF	520 CY	572 CY	676 CY	780 CY

Source: FEMA 329: Debris Estimating Field Guide

The **Hazus Flood Model Technical Manual** also has information about debris weights by flood depth and building occupancy class.

Debris removal costs are based on the costs of loading and hauling away debris, as well as landfill tipping (dumping) fees. The Texas Commission on Environmental Quality (TCEQ) reported that the average Texas statewide tipping fee was \$43.11 per ton in 2023³², equivalent to \$44.13 in 2024 dollars. FEMA uses a value of 4 cubic yards of woody debris per ton.³³



Using the **Homewyse Debris Removal Cost Calculator**, the number of labor hours required to break down debris and move it from a building site to the street was estimated as 1.4 hours for every cubic yard of debris, or 5.6 hours per ton. The value of time that homeowners must forgo to clean up debris can be estimated using the FEMA Value of Lost Time of \$43.11 per hour as of September 2024.³⁴

Debris removal costs can be calculated using the following equation:

Figure 7: Debris Removal Costs Equation

$$\begin{aligned}
 & \text{Debris Removal Costs} \\
 &= \sum \text{Tons of debris produced} * (\text{Tipping cost per ton} \\
 &+ (\text{Labor hours per ton of debris [5.6 hours]} * \text{Value of time per hour}))
 \end{aligned}$$

...where “Tons of debris produced” is calculated based on the size of each flooded structure and the VCM.

As with structure and content damages, debris removal costs should be estimated for each RI for both the Baseline and Project alternatives.

Reduced Flood Insurance Administrative Costs and Fees

A transaction cost is the fee for making an economic exchange. For flood insurance, transaction costs include all the material and labor costs associated with the general administration of a policy and transaction costs of administering an insurance claim.

As a result of a FRM project, there may be an associated reduction in the number of claims submitted to the National Flood Insurance Program (NFIP) for properties with a flood insurance policy. The NFIP experiences a reduction in the cost of administering a NFIP flood insurance policy when an insured property is acquired and maintained as open space in perpetuity, or if resultant flood damages are reduced through mitigation activities such as FRM projects. These savings in transaction costs can be considered a benefit separate from the reduction in flood damages. It is important to note that subject properties must have an active NFIP policy to be eligible for this benefit. The NFIP claim fees based on the claim/damage cost range is shown in Table 12.

Table 12: NFIP Claim Fees based on Claim/Damage Cost Range (2022 dollars)

Structure Damages	NFIP Claim Fee
\$0.01-\$1,000	625
\$1,000.01 - \$5,000	950
\$5,000.01 - \$10,000	1,230
\$10,000.01 - \$15,000	1,395
\$15,000.01 - \$25,000	1,515
\$25,000.01 - \$35,000	1,750
\$35,000.01 - \$50,000	2,050
\$50,000.01 - \$150,000	4.1% but not less than \$2,350
\$150,000.01 - \$250,000	3.9% but not less than \$6,150
\$250,000.01 - \$350,000	3.7% but not less than \$9,750
\$350,000.01 - \$550,000	3.2% but not less than \$12,950
\$550,000.01 - \$1,000,000	2.9% but not less than \$17,600
\$1,000,000.01 and higher	2.6% but not less than \$29,000

Source: FEMA. “Standard Economic Value Methodology Report.” Version 13.0.

The cost of NFIP claim administration for the Project Area can be calculated using the following equation:

Figure 8: NFIP Claim Administration Costs Equation

$$\text{NFIP Claim Administration Costs} = \sum_{\text{Structure with Active NFIP Policy}} \text{NFIP Claim Fee}$$

As with structure and content damages, NFIP administrative costs should be estimated for each RI for both the Baseline and Project alternatives.

6.2 Loss of Function

In the event of a flood, residents may be compelled to temporarily vacate their residences, and businesses may be required to vacate their premises. In a BCA, these disruptions are calculated as “loss of function” damages. Loss of function damages can include any disruption or displacement of ordinary circumstances if structures are flooded or at risk of flooding. These are primarily calculated based on the type of facility, whether residential, non-residential, or utility ([6.4 Utility Infrastructure](#)). The calculation of specific displacement costs can be broadly divided into residential and non-residential categories (each explained below), and each type of facility utilizes a different set of cost categories to precisely estimate the damages avoided (benefits) of the project.³⁵ The calculation of specific displacement costs can be broadly divided into two categories: residential and non-residential.

As with physical damages, a DDF can be used to estimate the number of days of displacement (loss of function) at various flood depths for residential and non-residential structures. While DDFs can be compiled from a variety of sources, FEMA’s BCA Toolkit and USACE provide the most commonly used DDFs, which are built into their software. Then, practitioners can estimate the number and cost of displacements. [Census Quick Facts](#) provides statistics such as the average number of people per household and the median rent in a specific region for all states and counties in the U.S. and cities and towns with a population over 5,000 people, which can be used to estimate the total cost of displacement.

Residential Displacements

Residential displacements include the following as disruption costs: preparing for potential evacuations; evacuating, cleaning and repairing damaged property after a flooding event; coordinating and supervising repairs; and making insurance claims. FEMA provides guidance on estimating each of these costs. For calculating displacement costs for different residential building types, consult [FEMA’s BCA Reference Guide, Appendix C](#).

There are five primary inputs when calculating residential displacements. First, the federal-lodging-per-diem-rate is the General Services Administration’s (GSA’s) per diem rate and assumes that a family of five can be accommodated in one standard hotel room. The 2025 standard rate for the State of Texas is \$110/day.

The meals and incidental expenditures (M&IE) GSA per diem rate is used for each person displaced in a residence. Similar to lodging-per-diem, the GSA determines a Standard Rate for M&IE, which is subject to change annually. For FY 2025, the standard rate is \$68 per person per day.³⁶ The cost of meals provided at home should be deducted from the M&IE rate; this is currently \$10 per person, per day.

The monthly rent of a tenant-occupied building is another input used when calculating residential displacement because it results in a loss of income to the owner of the property. The property owners or rent receipts can be used as sources in determining this cost. **Note that counting both displacement costs for the renter and the full loss of rental income to the property owner would be double-counting benefits; users should select whichever option provides more benefits.** Property owner information or Census data may be used to estimate the number of displaced building residents.

Finally, furniture rental, utilities, moving, and utility hook-up fees can be included as displacement costs.³⁷ Furniture rental and utilities are recurring costs, while moving and utility hook-up fees are considered one-time costs.

The costs of residential displacement can be calculated using the following equation:

Figure 9: Residential Displacement Costs Equation

Residential Displacement Costs

$$= \sum_{\text{Household}} \text{Number of Days Impacted} \\ * (\text{Lodging per diem} \\ + (\text{People per household} * (\text{M\&IE per diem} - \text{Cost of meals at home}))) \\ + \text{One Time Disruption Costs}$$

...where the “Number of Days Impacted” is obtained from the DDF and the depth of flooding as compared to the FFE.



Non-Residential

Non-residential loss of function costs are calculated as a one-time disruption cost with a recurring monthly rental cost for the duration of the displacement. These disruption costs are based on the type of non-residential structure (e.g., retail trade, wholesale trade, hospital, theater, school/library, college/university, etc.). Displacement costs can be calculated using the following equation:

Figure 10: Non-Residential Displacement Costs Equation

NonResidential Displacement Cost

$$= \sum_{\text{Structures}} (\text{Disruption cost} * \text{ft}^2) \\ + (\text{Rental cost} * \text{ft}^2 * \text{Displacement time in months})$$

As depicted, there are four primary inputs to the equation for non-residential displacement: duration of displacement (in months), square footage, monthly rent per square foot, and disruption cost. Square footage should be included in the basic structure data obtained from a source such as the local assessor’s office as previously discussed. Monthly rent can simply be taken as the monthly rent of a building paid to its owner, and like residential displacement, the property owner or rent receipts can be used as sources.³⁸ Disruption is calculated as the loss of building income. FEMA lists estimates of disruptions based on the building’s function; these are shown in Table 13.

Like physical damages, loss of function costs should be calculated for each RI for both the Baseline and Project alternatives. The total costs by RI are then annualized and compared between the Baseline and Project alternatives to calculate project benefits. The annualization process is described in [Section 6.12 Discounting and Annualization](#).

Table 13: Rental and Disruption Costs by Occupancy Class

Label	Occupancy Class	Rental Cost (2021) (\$/sq.ft./mo)	Disruption Costs (2021) (\$/sq.ft.)
RES1	Single Family Dwelling	0.91	1.10
RES2	Mobile Home	0.64	1.10
RES3a-f	Multi Family Dwelling	0.82	1.10
RES4	Temporary Lodging	2.74	1.10
RES5	Institutional Dormitory	0.55	1.10
RES1	Nursing Home	1.01	1.10
COM1	Retail Trade	1.55	1.46
COM2	Wholesale Trade	0.64	1.28
COM3	Personal and Repair Services	1.83	1.28
COM4	Professional/Technical/Business	1.83	1.28
COM5	Banks	2.29	1.28
COM6	Hospital	1.83	1.83
COM7	Medical Office/Clinic	1.83	1.83
COM8	Entertainment and Recreation	2.29	0.00
COM9	Theaters	2.29	0.00
COM10	Parking	0.46	0.00
IND1	Heavy Industrial	0.27	0.00
IND2	Light Industrial	0.37	1.28
IND3	Food/Drugs/Chemicals	0.37	1.28
IND4	Metals/Mineral Processing	0.27	1.28
IND5	High Technology	0.46	1.28
IND6	Construction	0.18	1.28
AGR1	Agricultural Building	0.91	0.91
REL1	Church/Membership Organization	1.37	1.28
GOV1	General Services	1.83	1.28
GOV2	Emergency Response	1.83	1.28
EDU1	Schools/Libraries	1.37	1.28
EDU2	College/Universities	1.83	1.28

Source: FEMA. "Benefit-Cost Analysis Sustainment and Enhancements Standard Economic Value Methodology Report," Version 13.0.



6.3 Agriculture

Floodwaters can significantly damage agricultural lands and associated crop and livestock production; the reduction of those damages would constitute an economic benefit for a proposed project. In addition, FRM projects that also increase water supply could increase irrigation availability, and therefore increase crop yields. Agricultural benefits can also include reductions in production costs and/or the values of increased production of crops.

Agricultural benefits are calculated based on increased/decreased crop yields and/or increased/decreased production costs under the Baseline and Project alternatives. Agricultural data such as acres harvested, yields, and prices by crop type and county can be obtained from the U.S. Department of Agriculture's (USDA's) **NASS** system.³⁹

The TWDB is currently developing a model to calculate agricultural flood damages in Texas. More information about that effort can be found on the [TWDB website](#).



6.4 Utility Infrastructure

Flood impacts on utility infrastructure include both the physical damage to the structures themselves and associated impacts due to lack of service to customers. Floods can cause sewage to back-up into homes, contaminate drinking water, interrupt power supply and communications networks, and require emergency repairs and replacement of damaged treatment, conveyance, and pumping equipment. Emergency costs associated with utility service outages also include costs to restore service (labor and capital costs) and additional operating costs incurred by the utility (e.g., flood fighting costs). Additional operating costs for the utility include overtime or costs incurred for employing additional utility workers above what is normally required.

FEMA's default values for the value of service per person, per day are \$213 for electrical, \$150 for potable water, \$71 for wastewater, and \$151 for communications, in 2023 dollars. (All values are updated to current year dollars in the TWDB Flood BCA Calculator.)⁴⁰

The cost of loss of function associated with utilities can be calculated using the following equation:

Figure 11: Utility Infrastructure Loss of Function Costs Equation

Utility Infrastructure Loss of Function Costs

$$= \sum_{\text{utility}} \text{Population impacted} * \text{Days without service} * \text{Value of service}$$

Utility loss of function costs should be calculated for each RI for the Baseline and Project alternatives. The total costs by RI can then be annualized and compared between the Baseline and Project alternatives to calculate project benefits. The annualization process is described in [Section 6.12 Discounting and Annualization](#).

6.5 Transportation Infrastructure

Transportation infrastructure can be seriously affected by flooding in several ways, including the inundation of low-lying roadways or railways, the erosion of bridges, damage to the surfaces of the roadways, and damage to cars, buses, and trains.

Floodwater impacts to transportation infrastructure include both damage to the infrastructure itself and the impacts of closures on users through detours and delays.

Detours and Delays

Flooded streets are generally considered to be impassable once they are covered by 6 inches of water. When streets are impassable, drivers must detour to get to their destinations, which incurs an additional travel cost. If a project reduces flooding to less than 6 inches of water or reduces the duration that a roadway is flooded and thus the amount of traffic impacted, the travel time and operating costs saved from extended detour prevention can be calculated and considered benefits.

Decreased travel mileage from reduced detours can also result in emissions savings based on vehicle emission rates per mile and safety savings based on injury and fatal crash rates. In addition to passenger vehicles, similar impacts to transit and commercial vehicles should also be considered.

Emissions rates can be found from various sources, including EPA data. Crash rates are published by the U.S. Department of Transportation (USDOT) and are calculated per 100 million vehicle miles traveled (VMT).⁴¹ Many default values for associated benefit calculations can be found in the USDOT's [Benefit-Cost Analysis Guidance for Discretionary Grant Programs](#).

The costs of detours and delays associated with roadway flooding can be calculated using the following equations:

Figure 12: Detour Costs Equation

$$\begin{aligned} \text{Detour Costs} = & (\text{Vehicles impacted} * \text{Additional detour mileage} \\ & * \text{Vehicular operating cost per mile}) \\ & + (\text{Roadway users impacted} * \text{Additional detour time} * \text{Value of time}) \end{aligned}$$

Where

$$\text{Vehicles impacted} = \text{Daily traffic} * \frac{\text{Hours Impacted}}{24}$$

And

$$\text{Roadway users impacted} = \text{Vehicles impacted} * \text{Average vehicle occupancy}$$

Detour costs should be calculated for each RI for the Baseline and Project alternatives. The total costs by RI are annualized and compared between the Baseline and Project alternatives to calculate project benefits. The annualization process is described in [Section 6.12 Discounting and Annualization](#).

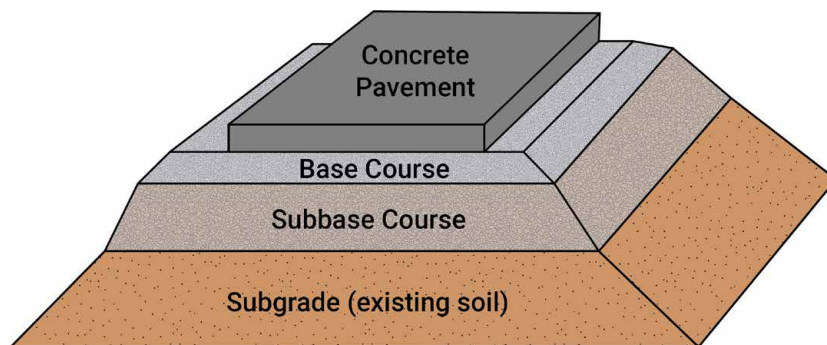


Infrastructure Damages

In addition to the costs of detours and delays, floodwaters with sufficient velocity can impact transportation infrastructure such as roads and bridges as well. Even low-velocity floodwaters can saturate pavement and subgrades, reducing the overall service life of pavement. According to both experimental and analytical studies, resilient modulus of unbound layers of pavement decreases immediately after flooding but gains strength again and gradually recovers in terms of stiffness as floodwaters recede. However, such flood-induced deformations do not return to zero, and unbound layers reach a new equilibrium stress-strain state. Flood-induced deformations contribute to the accumulated deformation of the pavement and can result in service life reduction.⁴²

A literature review conducted by TxDOT on the impacts of flooding on pavements explored several analyses of the short-term effects of flooding on the stiffness and capacity of pavements. One reported that damage assessments on flooded pavement in New Orleans after Hurricane Katrina noted that flooded pavements had higher deflections, lower structural numbers, and lower subgrade resilient modulus compared to unflooded pavements. Another reported that evaluations of the impact of 2011 Missouri River flooding on paved and unpaved roadways in Iowa found a 20-30 percent reduction in subgrade modulus even 6-8 months after flooding.⁴³

Figure 13: Roadway Pavement and Subgrades



TxDOT also conducted a pilot project, the **Asset Management, Extreme Weather, and Proxy Indicators Pilot**, to characterize the risk of flooding to road infrastructure in Houston and thus provide better inputs for pavement engineers estimating the damage caused by these events. Pavement analysis completed for this study found that thinner pavement structures, particularly those without treated subgrades and with asphalt of less than two inches, were particularly vulnerable to flooding. If thinner pavement sections are heavily trafficked during flood response, therefore, immediate pavement damage can be expected that will likely require immediate reconstruction. Although specific dollar values of damage-per-flood-event were not calculated in this study, more information about the types of pavements assessed and the impacts of flooding on their **service lives** can be found in the linked report.

Bridges can fail in a flood via two different failure mechanisms: scour undermining the bridge supports or abutments, or openings being blocked by flood borne debris and causing the bridge to fail catastrophically under the buildup of water.

Infrastructure damages are highly project-specific; therefore, no generic formula is provided. If a project is expected to prevent infrastructure damages, damage costs should be calculated for each RI for the Baseline and Project alternatives.





Emergency Response Costs

Emergency response costs can be incurred as a direct result of flooding from detours and delays. These costs are highly local and project-specific; project sponsors should work with local agencies to determine historical emergency response costs and their applicability to future events. If a project is expected to reduce flooding enough to impact emergency response needs, then reduced emergency response costs can be included as a benefit. It is important to only include these costs in the benefit calculations if they can be reasonably foreseen to be reduced by the implementation of the project.

Potential sources to assist with labor costs include the Bureau of Labor Statistics' (BLS) [Occupational Employment and Wage Statistics](#). Some labor categories that could be relevant to emergency response costs are included in Table 14.

Table 14: Texas Median Average Wage for Emergency Response Occupations (2023 dollars)

Occupations involved in flood/emergency response	Texas Median Wage
Police and Sheriff's Patrol Officers	\$35.58
Firefighters	\$28.79
Emergency Medical Technicians	\$17.24
Paramedics	\$25.02
Emergency Management Directors	\$45.27

Source: BLS. "Occupational Employment and Wage Statistics – Texas." 2024.

The costs of emergency response associated with flooding can be calculated using the following equation:

Figure 14: Emergency Response Costs Equation

$$\text{Emergency Response Costs} = \sum_{\text{Occupation}} (\text{Number of hours required} * \text{Median wage per hour})$$

Emergency response costs should be calculated for each RI for the Baseline and Project alternatives. The total costs by RI are annualized and compared between the Baseline and Project alternatives to calculate project benefits. The annualization process is described in [Section 6.12 Discounting and Annualization](#).

6.6 Health & Safety

Floods can represent a significant threat to the health and safety of the public, including fatalities caused by the flood itself (usually related to the velocity of floodwater), loss or delay of emergency services due to flooded streets, injuries caused by debris cleanup, health impacts of exposure to contaminated floodwaters and mold, and the mental health impacts of experiencing a flood event. If a project can be shown to reduce injuries or fatalities, the lives saved and/or injuries avoided can be quantified and included in project benefits.

Unfortunately, these impacts are often not considered in BCAs, or are only considered under specific circumstances. FEMA has developed values for the costs of mental health impacts and a methodology for evaluating the impact of a loss or delay of emergency services for specific conditions; however, FEMA only allows loss-of-life-avoided benefits to be included in a BCA for events with very low warning times (e.g., flash flood events, tornados), or for projects specifically serving personnel who must remain behind following an evacuation order (e.g., hurricane safe rooms for emergency personnel).⁴⁴

The value of avoiding injuries and fatalities is based on the Value of a Statistical Life (VSL). The official federal guideline for determining and using a reasonable VSL is found in **OMB Circular A-4**. Version 13 of the **FEMA Benefit-Cost Analysis Sustainment and Enhancements: Standard Economic Value Methodology Report** recommends using a VSL of \$13.2 million, with a base year of 2023.

Non-fatal injuries are far more common during flood events than fatalities. Due to a lack of data regarding willingness-to-pay to avoid the range of potential injuries, a standardized method is used to interpolate costs of expected outcomes, scaled in proportion to the VSL. Relative value coefficients for preventing injuries of varying severity and duration can be based on the Abbreviated Injury Scale (AIS), which categorizes injuries into six levels, ranging from AIS 1 (Minor) to AIS 6 (Unsurvivable).⁴⁵ When an injury level is unknown, USDOT BCA Guidance recommends using an economic cost of \$229,800 per injury (in 2023 dollars). AIS codes, injury levels, examples of selected injuries, and the economic cost per injury are shown in Table 15.

Table 15: AIS Injury Levels and Economic Costs (2023 dollars)

AIS Code	Injury Level	Selected Injuries	Fraction of VSL	Economic Cost per Injury
AIS 1	Minor	Superficial abrasion or laceration of skin; digit sprain; first-degree burn; head trauma with headache or dizziness (no other neurological signs)	0.003	\$40,000
AIS 2	Moderate	Major abrasion or laceration of skin; cerebral concussion (unconscious less than 15 minutes); finger or toe crush/amputation; closed pelvic fracture with or without dislocation	0.047	\$620,000
AIS 3	Serious	Major nerve laceration; multiple rib fracture (but without flail chest); abdominal organ contusion; hand, foot, or arm crush/amputation	0.105	\$1,386,000
AIS 4	Severe	Spleen rupture; leg crush; chest-wall perforation; cerebral concussion with other neurological signs (unconscious less than 24 hours)	0.266	\$3,511,000
AIS 5	Critical	Spinal cord injury (with cord transection); extensive second- or third-degree burns; cerebral concussion with severe neurological signs (unconscious more than 24 hours)	0.593	\$7,828,000
AIS 6	Unsurvivable	Injuries that result in death	1.000	\$13,200,000

Source: FEMA. "Benefit Cost Analysis Sustainment and Enhancements, Standard Economic Value Methodology Report." Version 13.0. September 2024.

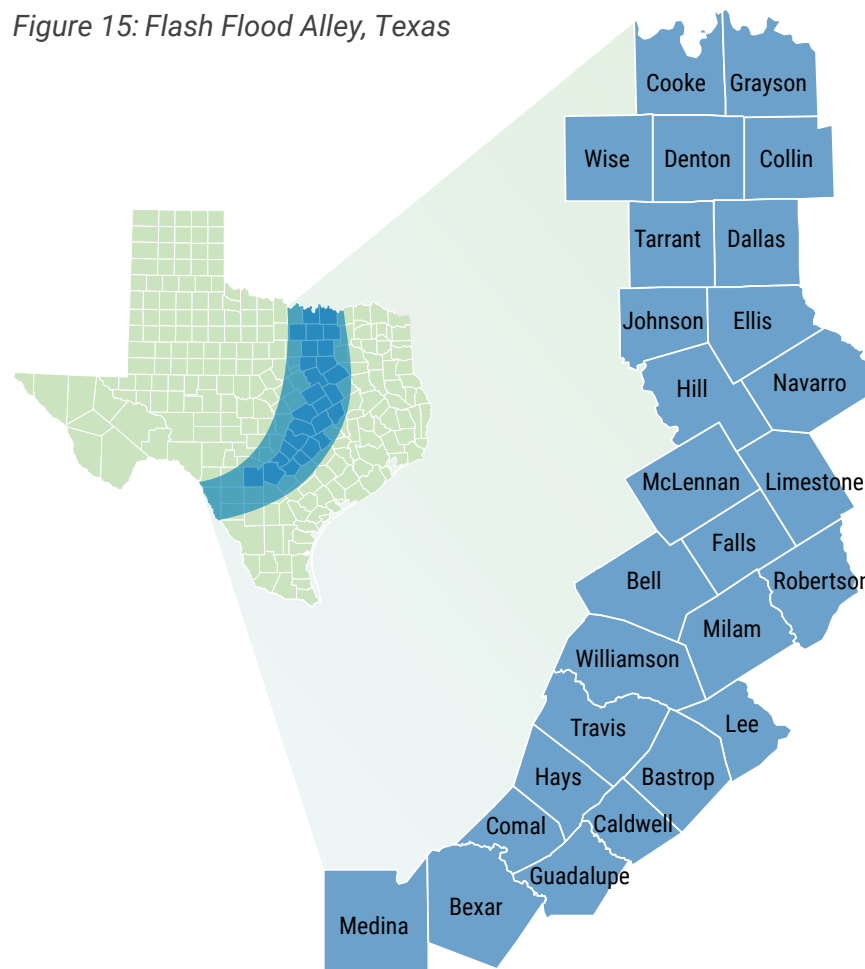
This BCA Guidance Document presents research related to health and safety impacts of floods from a variety of public sources. Because these benefits do not have standard values commonly used by federal agencies, more detail about the source(s) of the data are included in this section. However, it is important to note that these methodologies and data points should be considered preliminary. More research is recommended for this benefit category due to limited data.

Direct Floodwater Fatalities

The speed at which a flood occurs has a major impact on whether people will be exposed to floodwater, and therefore the risk of death or serious injury. When a flood's onset is gradual and its rate of rise is slow, people have time to take action and, if necessary, leave the flood risk area. When flooding occurs very rapidly, people have very little time to respond. One of the most dangerous types of flooding, therefore, is flash flooding.

The Hill Country and Central regions of Texas have a greater risk of flash flooding than most regions of the United States.⁴⁶ These regions of Texas are collectively called Flash Flood Alley (Figure 15) because of the area's steep terrain, shallow soil, and unusually high rainfall rates. Heavy rains can quickly transform into walls of fast-moving water with great destructive potential. Flash Flood Alley basically follows the edge of the Balcones Escarpment in central Texas, a topographic feature that separates the Texas Hill Country from the Eastern Coastal Plains.

Figure 15: Flash Flood Alley, Texas



Source: San Antonio River Authority. <https://www.sariverauthority.org/be-river-proud/flood-risk>.

Over a nearly 50-year period in the United States, Texas suffered more than twice the number of flash flood fatalities as the next-ranked state. In 2007, Texas suffered the most flood deaths in the nation (46 out of 89 total), with 767 swift water rescues recorded by the State Fire Marshall's office.⁴⁷ Over the 20-year period from 2004 to 2023, 18 percent of all U.S. flood fatalities occurred in Texas, and 52 percent of Texas flood fatalities occurred in vehicles. Only one year over this time period (2011) had no flood fatalities in Texas.⁴⁸

An average adult is unable to stand in still water with depth of about 4 feet or greater. For flowing water, the depth at which a person can stand is much less. Some people will be at risk when the water depth is only 1.5 feet if the velocity is 2 mph (3 feet per second [fps]). If the velocity increases to 4 mph (6 fps), some people will be unable to stand in a depth of water of only 1-foot. Most people will be unable to stand when the velocity is 4 mph and the depth is 2-feet. The chances of people being unable to stand in floodwater is increased if the ground is uneven or there are holes in the ground beneath the water surface. Once people are unable to stand, there is a high risk of death or serious injury.⁴⁹

The chance of people being exposed to floodwater depends on where they are: for example, outdoors on foot, outdoors in a vehicle, or in a building. The degree to which people are exposed to floodwater also depends on whether flood warnings are received and acted upon. The ability of people to respond to a flood depends on their physical condition. Those who are elderly, disabled, and/or have a long-term illness find it more difficult to deal with flood situations, and are therefore more prone to death or serious injury.⁵⁰

The United Kingdom’s Department of Environment, Food, and Rural Affairs (DEFRA) defines flood risks to people as “a combination of flood hazard, area vulnerability, people vulnerability, and number of people at risk.”

- » **Flood hazard** depends on flow depth and velocity;
- » **Area vulnerability** depends on the nature of the area (including types of buildings), availability of flood warnings, and speed of flood onset; and
- » **People vulnerability** depends on the age and physical condition of the people exposed to the flood.

More information about the DEFRA methodology for calculating flood risks to people can be found in the [DEFRA Flood Risks to People Phase 2 Guidance Document](#). Note that, because this is a UK publication, distances and velocities are measured in meters.

In the U.S., the impacts of flash flooding are often studied based on dam failures. Loss of life resulting from dam failure is highly influenced by the number of people occupying the dam failure flood plain, the amount of warning that is provided to the people exposed to dangerous flooding, and the severity of the flooding. This logic can also be applied to other types of flash flooding.

The U.S. Department of the Interior’s Bureau of Reclamation Dam Safety Office developed the [RCEM – Reclamation Consequence Estimating Methodology: Guidelines for Estimating Life Loss for Dam Safety Risk Analysis](#) (the RCEM) in 2015. The RCEM presents graphical estimates of fatality rates based on depth x velocity (DV) in ft²/sec and the quality of the warning given to the population-at-risk (PAR). The PAR, DV, and warning time estimates should be estimated for each potentially lethal flood zone (PLFZ), which are defined by the maximum flood depth and DV. The fatality rates by DV for “little or no warning” and for “adequate warning” are shown in Figure 16 and Figure 17.



Figure 16: Fatality Rate vs DV, Little or No Warning

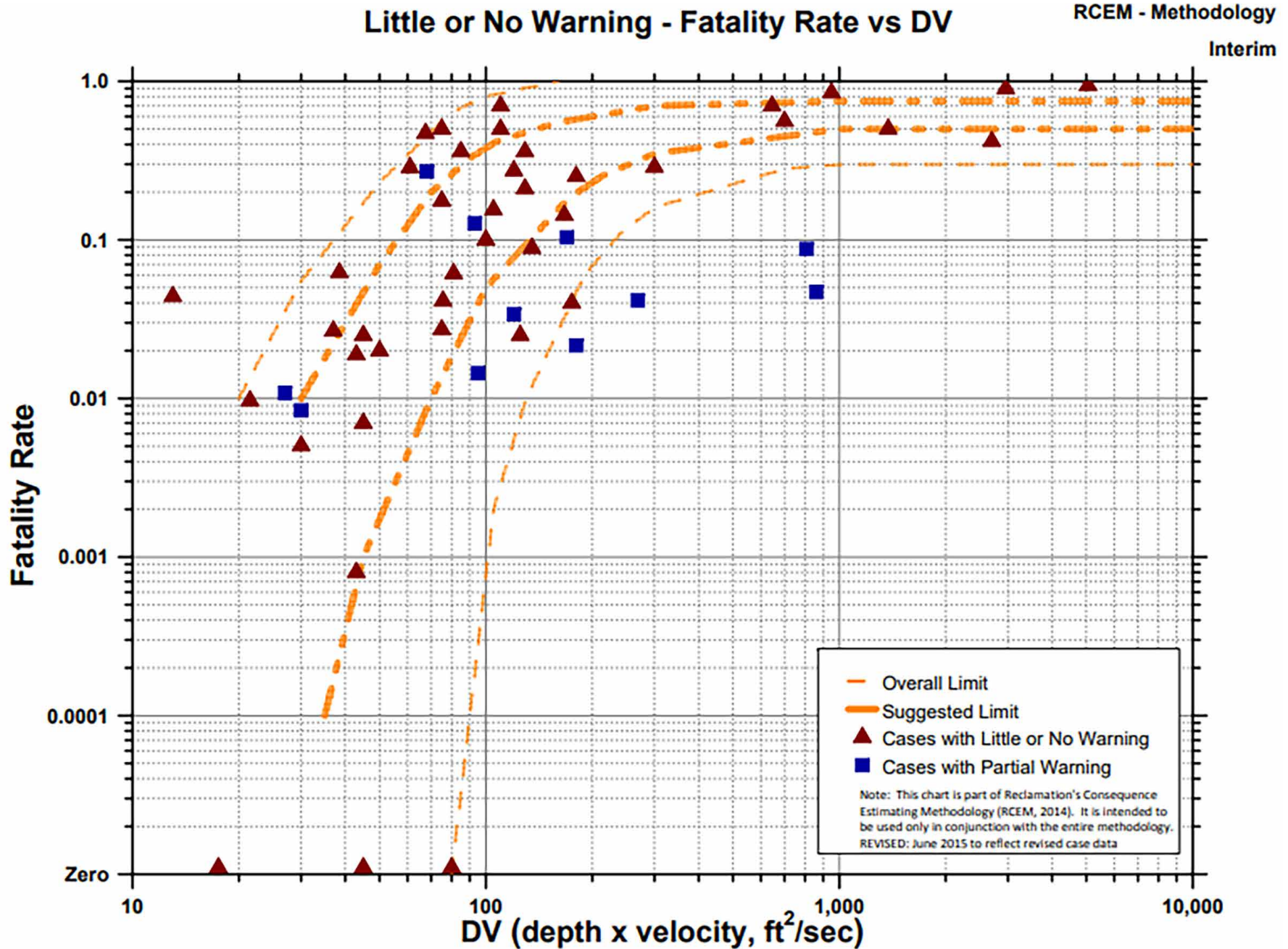
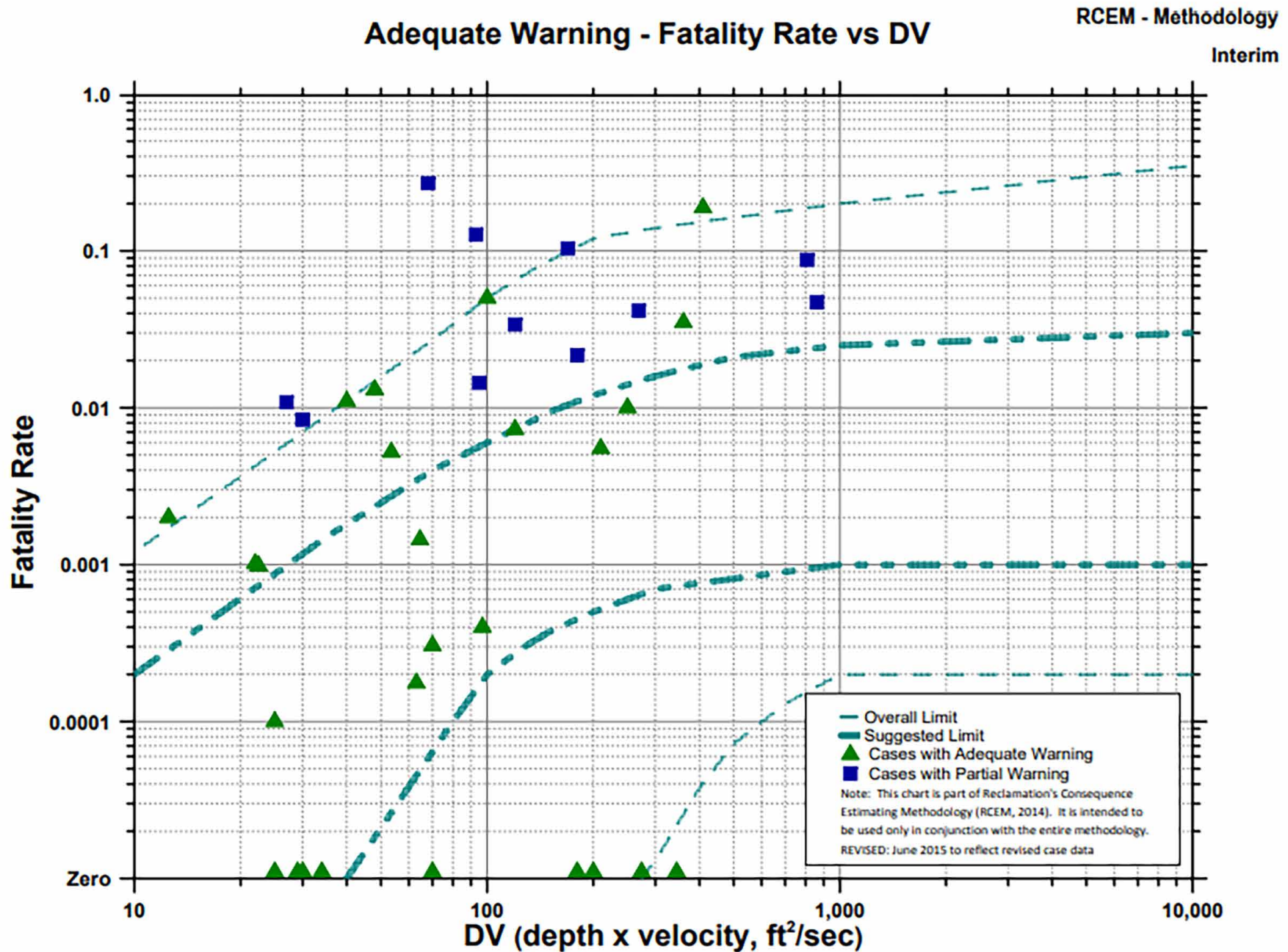


Figure 17: Fatality Rate vs DV, Adequate Warning



The costs of flash flood fatalities can be calculated using the following equation:

Figure 18: Cost of Flash Flood Fatalities Equation

$$\text{Cost of Flash Flood Fatalities} = \sum_{PLFZ} PAR * \text{Fatality Rate} * VSL$$

...where the fatality rate is a function of the DV and the warning time.

In addition to the RCEM, there are several other acceptable methods and models that can be used to estimate the PAR and loss of life related to flash flooding. These include:

- » **LifeSim (USACE)**
 - » Considers warning time, warning diffusion, PAR's protective action and evacuation potential, and detailed flood dynamics
 - » Simulates the evacuation process and assesses reactions
 - » Requires H&H data, including a time series of depth and velocity
- » **HEC-FIA (USACE)**
 - » Simplified LifeSim method
 - » Typically requires stream centerline, structure/population data, and impact area
 - » Requires H&H data
- » **DSS-Wise/DSS-Wise Lite (FEMA)⁵¹**
 - » Web-based, automated 2D dam-break flood modeling and mapping
 - » Automated input data preparation using national databases (USGS, NED DEM, levees, bridges, classified land-use/cover)
 - » Real-time error checking allows the user to quickly set up and run dam and levee breach scenarios

Note that DSS-Wise Lite does not directly estimate fatalities. However, the **Human Consequences Module (HCOM)** does

use Census population data and **LandScan USA** nighttime and daytime population data by Oak Ridge National Laboratory to provide four types of analysis:

1. Flood Hazard Mapping for humans
 - 1.1. Population caught outdoors
 - 1.2. Population caught indoors
2. Mapping of PLFZ for humans
 - 2.1. PLFZ for children
 - 2.2. PLFZ for adults
3. Analysis of the evolution of inundation areas by hazard classes
4. Analysis of PAR numbers by interfacing results from DSS-Wise Lite with population data
 - 4.1. Nighttime PAR using LandScan USA nighttime population
 - 4.2. Daytime PAR using LandScan USA daytime populations
 - 4.3. PAR analysis using census block data

Low Water Crossings

Low water crossings (LWCs) pose a unique threat, as many flood-related deaths involve motorists that are trapped in their vehicles or washed away. A LWC is a low-elevation roadway crossing over a waterway that is dry for most of the year when flow is low but is submerged during high-flow conditions or floods. For the purposes of this document, a LWC could also include a highway dip or underpass.

For Texas specifically, fatalities related to LWCs poses a significant threat. In many of the Texas fatalities cited previously, victims, not wanting to take a lengthy detour, ignored barricades and tried to drive across a flooded street or LWC.⁵² Many more are rescued every year from strandings on flooded roads, having underestimated the depth and velocity of the water and believing their vehicles to be large enough to drive through, or perceiving pressure from passengers and/or their need to go to work or get home.⁵³

An existing body of literature shows that people's decision not to avoid flooded roads varies based on specific risk perceptions. A 2018 review revealed that, despite its importance as a cause of flood-related mortality, motor-vehicle-related drowning, as well as the risk perceptions and motivations of people in undertaking this risky behavior, remain poorly understood. The literature suggests that individuals' decisions to drive into or avoid flood waters are motivated by their perceptions of the risk and awareness of flood threats. People's decisions to drive into or turn back from floodwaters are identified as consequences of both their risk perception and the combined impact of all other factors (e.g. individual, social, environmental) that interdependently contribute to shape their decision-making.⁵⁴ The total number of fatalities tends to be higher in more densely populated areas, but fatality rates accounting for population size tend to be higher in rural areas where lack of infrastructure limits detour route options.⁵⁵

In a survey commissioned by the UK's Environment Agency and its Automobile Association, approximately half of over 19,000 motorists surveyed admitted that they would take the risk of driving through floodwaters rather than find a safer route.⁵⁶ An Australian survey found that people were significantly more willing to drive through 20 cm (~8 inches) of water compared to 60 cm (~24 inches).⁵⁷



Another survey of 714 adult participants in the mid-Atlantic of the U.S. found that the likelihood of a motorist continuing to drive a flooded road increases with the time required to take an alternate route. This statistically significant result is logical as it implies that motorists tend to avoid alternate routes to avoid costs associated with driving extra miles.⁵⁸

This survey also explored motorist responses to different flooding hazard signage and found that participants were willing to drive up to an additional 18.5 minutes to avoid flooded roads in response to a simple "Road Flooded" sign. Furthermore, if that "Road Flooded" sign included information about the water being less than 4 inches deep, respondents preferred to remain on the flooded route. In contrast, motorists were much more cautious in response to a "Road Flooded" sign stating that the water was more than 12 inches deep and were willing to drive up to approximately 40.6 additional minutes to avoid such a risk. In response to road signs reading "Road Flooded" with a "car symbol with no wave symbol," or with "a car symbol with three wave symbols," participants were willing to drive an additional 27.1 min or 35.6 minutes, respectively, to avoid the corresponding flooded road.⁵⁹

The Texas Transportation Institute (TTI) found similar inclinations when it surveyed 8 focus groups encompassing a total of 74 drivers.⁶⁰ When the TTI asked these drivers the question, "When would it be all right to drive through water that's overflowing a road?", only six participants (8 percent) responded "never." When focus group participants were asked to define what depth of floodwater would be "too deep" to cross, answers varied, from "three or less" inches, to "six to eight" inches, to "top of tires," to "tailpipe height," and finally to "too deep to walk through."

The TTI surveyors also presented photos to participants and asked them whether or not they would be willing to proceed on a roadway as shown. Depths that drivers considered hazardous varied from 3 inches to over 2 feet. In general, the percentage of participants willing to proceed decreased as the depth and velocity increased. However,

less than 25 percent of drivers in the groups said that they considered a “flooded” road to be automatically impassable. Additionally, and in keeping with the survey results noted previously, participants’ willingness to detour depended on the length of detour.

Overall, about 90 percent of drivers in the TTI focus groups said that they would be likely, depending on their own set of criteria, to proceed through water covering a road. However, only one (1) out of the 74 (1.4 percent) responded that they would attempt to cross a LWC with flowing water that had a depth that was difficult to ascertain. A literature review did not reveal estimates on the number of vehicles attempting to cross a LWC that would be successful at varying flood depths.

Based on a review of the surveys detailed above, estimates were developed for what percent of drivers would attempt to cross a flooded roadway based on flood depths and detour times (assuming low-to-no-flow velocities). These are shown in Table 16. This data and methodology should be considered preliminary, and more research needs to be conducted in this area of flood-risk-related decision-making and impacts.

Table 16: Estimated Percent of Drivers Attempting to Cross a LWC Detour Times (minutes)

Depth	<5 (min)	5 to 20 (min)	20 to 40 (min)	40 to 60 (min)	>60 (min)
<6"	92%	94%	96%	98%	99%
6"	10%	14%	18%	22%	25%
12"	5%	6%	8%	9%	10%
18"	1%	2%	3%	4%	5%
24"	0.5%	1.1%	1.8%	2.4%	3.0%
30"	0.2%	0.8%	1.2%	1.6%	2.0%
>36"	0%	0.6%	0.9%	1.1%	1.4%

This data and methodology should be considered preliminary, and more research needs to be conducted in this area of flood-risk-related decision-making and impacts.



Current FEMA and USACE FRM policies do not include benefits from reducing LWC casualties. In order to estimate a possible reduction in fatalities that could be attributed to the elimination of a LWC, the analyst needs to estimate the number of drivers that would attempt to cross that LWC and how many of those would be unsuccessful. The number that would attempt to cross a LWC is dependent upon average annual daily traffic (AADT) counts and the availability of detour routes. AADT counts for many state, county, and city streets in Texas are available from the [TxDOT Traffic Count Maps](#). These daily traffic counts can be divided by 24 to estimate hourly counts that can be applied to the number of hours a LWC would be flooded, to estimate the number of drivers impacted during each flood event in the Baseline and Project alternatives. USDOT Guidance estimates the average occupancy of passenger vehicles at 1.52 people per vehicle.

Once the number of people attempting to cross a LWC has been estimated, the analyst needs to estimate the number of attempts that would be unsuccessful, the number of rescue attempts made, and the number of fatalities and injuries that result. The percent of attempted crossings that would be unsuccessful is dependent upon the depth and velocity of the water and the characteristics of the vehicle.

A literature review did not reveal estimates on the number of vehicles attempting to cross a LWC that would be successful at varying flood depths. Commonly cited statistics say that 6 inches of water will reach the bottom of most passenger cars, causing loss of control and possible stalling; a foot of water will float many vehicles; and 2 feet of rushing water can carry away most vehicles, including sport utility vehicles (SUVs) and pick-up trucks. This does vary, as each vehicle has a specific “fording” depth, which is the depth of water that a car can pass through without taking on water (assuming low flow velocities). Forging depth is measured as the distance between the point touched by the car’s tires and the engine’s air intake system.

Kramer, et.al (2016) reported that the typical fording depths of passenger cars ranged from 30 to 50 cm (11.8 to 19.7 inches), while the fording depths of emergency and off-road vehicles ranged from 60 to 120 cm (23.6 to 47.2 inches). In the context of this study, fording depths of 50 vehicles were collected mainly from manufacturer’s data and literature. An analysis of 50 vehicles (25 passenger cars and 25 emergency and off-road vehicles)⁶¹ showed that 28 percent of the emergency vehicles had fording depths of 60 cm (23.6 inches) and 12 percent had fording depths of 120 cm (47.2 inches), while 48 percent of the passenger vehicles had fording depths of 30 cm (11.8 inches) and 8 percent had fording depths of 50 cm (19.7 inches).

In Texas, 40.6 percent of vehicles on the road are SUVs and 19.2 percent are pickup trucks.⁶² The fording depths for some of these vehicles can be as high as 30 to 34 inches (e.g., Ford F-150 Raptor,⁶³ Ram 2500 Power Wagon,⁶⁴ Jeep Wrangler⁶⁵). After-market lifted suspensions can further increase fording depths of individual vehicles.

An attempted LWC crossing that is “unsuccessful” can result in emergency response costs from the rescue, property damage of the vehicle, and injuries or fatalities of vehicle occupants. Showalter and Lu (2010)⁶⁶ estimated rescue costs at approximately \$2,000 per hour and assumed that each swift water rescue required 3 hours. Updating this estimate to 2025 dollars produces estimated costs of approximately \$8,500 per rescue. However, the authors noted that these costs are highly variable and only 4 of 36 fire departments were willing and able to provide even an approximate cost estimate. Additionally, this only represented fire department costs and did not include expenditures by other public service organizations such as police, ambulances, life flights, etc.

Vehicle property damage can be estimated using the average price of a used vehicle from a source such as the Kelly Blue Book or Edmunds. Edmunds has reported that the average transaction price of used vehicles was \$27,177 in Q3 2024.⁶⁷

Data from the Texas Fire Marshal’s Office shows that between 2005 and 2014, 3,256 swift water rescues were reported from 54 percent (136 of 254) of Texas counties. Over half occurred in counties located in the region known as Flash Flood Alley, described previously.⁶⁸ This is equivalent to approximately 325 rescues per year.

Between 1959 and 2019, there were 570 vehicle-related flood fatalities, representing 58 percent of total flood fatalities.⁶⁹ This is equivalent to 9.5 vehicle-related flood fatalities per year. Using an average of 325 rescues and 9.5 fatalities per year, approximately 2.8 percent of unsuccessful crossing attempts resulted in fatalities. The benefit of avoiding injuries and fatalities can be valued using Table 15.

The overall cost of injuries and fatalities at LWCs can be calculated using the following equation:

Figure 19: Cost of Injuries and Fatalities at LWC Equation

$$\begin{aligned} & \text{Cost of Injuries and Fatalities} \\ &= \text{Normal traffic during closure period} \\ & \quad * \text{Percent of Traffic Attempting to Cross the LWC} * (1 - \text{Percent Successful}) \\ & \quad * \text{Cost of Unsuccessful Crossing Attempt} \end{aligned}$$

Where

$$\text{Normal traffic during closure period} = \text{Daily traffic} * \frac{\text{Length of closure in hours}}{24}$$

And

$$\begin{aligned} & \text{Cost of Unsuccessful Crossing Attempt} \\ &= \text{Cost of property damage} + \text{Cost of swift water rescue} \\ & \quad + (\text{Average vehicle occupancy} * \text{Percent fatalities} * \text{VSL}) \\ & \quad + (\text{Average vehicle occupancy} * \text{Percent nonfatal injuries} \\ & \quad * \text{Economic cost of injuries}) \end{aligned}$$

Injuries and fatalities at LWCs should be calculated for each RI for the Baseline and Project alternatives. The total costs by RI can then be annualized and compared between the Baseline and Project alternatives to calculate project benefits. The annualization process is described in [Section 6.12 Discounting and Annualization](#).

Loss of Emergency Services

In addition to the direct costs of increased emergency response activities related to flooding, a flood-impacted area may also experience a loss or delay of normal emergency services. Emergencies such as cardiac events or property fires continue to occur throughout a flood event, and increased response times can have real, negative impacts. FEMA has developed equations to estimate the increased likelihood that someone will die due to a fire or a cardiac event when there is a delay in emergency services, which can be included in a BCA. The most up-to-date formulas and values for these calculations, as of March 2025, can be found in Sections 2.5, 2.6, and 2.7 of the [FEMA Benefit-Cost Analysis Sustainment and Enhancements, Version 13.0](#).

Access to other critical health services, such as dialysis or chemotherapy, can also be disrupted due to flooded streets. There are currently no methods available to estimate the magnitude of this impact.

Evacuation, Cleanup, and Repair Injuries

A survey conducted by the Centers for Disease Control and Prevention (CDC) of injuries from evacuation, cleanup, and repair of damaged properties following Hurricane Sandy found that 10.4 percent of respondents reported a storm-related injury. Of those injured, 25.1 percent reported visiting a hospital, emergency department (ED), or doctor; while 16.9 percent received other treatment.⁷⁰ The most common types of injuries reported were leg/arm/hand cuts and leg/back strains. The percentages of the PAR reporting injuries are shown in Table 17.

Table 17: Injuries Reported Following Hurricane Sandy

Evacuation Status	Depth of Flooding	Percent Injured	Percent visiting hospital, emergency department, or doctor	Percent receiving other treatment
Did Not Evacuate	No Flooding	3.0	34.8	4.3
Did Not Evacuate	<3 feet	11.5	25.0	28.6
Did Not Evacuate	≥3 feet	25.3	8.3	25.0
Did Evacuate	No Flooding	5.8	29.6	11.1
Did Evacuate	<3 feet	15.9	19.3	19.3
Did Evacuate	≥3 feet	26.1	30.6	16.1

Source CDC. *Nonfatal Injuries 1 Week After Hurricane Sandy – New York City Metropolitan Area, October 2012. Morbidity and Mortality Weekly Report. 24 October 2014.* <https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6342a4.htm#>

These percentages can be applied to the population protected by the proposed FRM project to estimate the number of injuries the project may prevent.

In addition to the economic value of the injuries based on the percentage of the VSL shown in Table 15, the value of preventing an injury can also include the cost of medical treatment. According to the National Safety Council, the cost per medically consulted injury in 2021 was \$42,000.⁷¹

The cost of injuries can be calculated using the following equation:

Figure 20: Cost of Flood Injuries Equation

$$\text{Cost of Injuries} = \text{PAR} * \text{Percent Injured} * \text{Cost of Injury}$$

Injuries should be calculated for each RI for the Baseline and Project alternatives. The total costs by RI can be annualized and compared between the Baseline and Project alternatives to calculate project benefits. The annualization process is described in [Section 6.12 Discounting and Annualization](#).

Infectious Diseases and Other Health Impacts

In the days and weeks following floods, the threat of contracting an infectious disease is high. Public health studies often reveal an uptick in gastrointestinal diseases after floods. Standing water can become a breeding ground for mosquitos, which carry viruses such as West Nile, dengue, chikungunya, and Zika. Sampling in floodwaters in Houston following Hurricane Harvey in 2017 also revealed a host of bacteria and chemicals from untreated sewage runoff, household chemicals, and industrial petrochemicals. One woman from a Houston suburb died after coming into contact with flesh-eating bacteria in water.⁷²

Following Hurricane Harvey, a grassroots initiative of academic institutions, local public health agencies, and community stakeholders established the Hurricane Harvey Registry to collect community health and housing data and establish a baseline understanding of the risks of longer-term environmental health effects from storms. Following flood events in May and September of 2019, this was renamed the Texas Flood Registry (TFR).⁷³

Multi-variable logistic regression of the TFR showed that respondents whose homes had flooded had increased odds of a myriad of adverse health effects compared to those whose homes had not flooded.

Increased incidence of health issues must be compared against a baseline, or the background rate of those conditions that occur in the population in the absence of flood conditions. In 2021, the CDC reported that the number of annual ED visits per 100 persons was 42.7, an increase from the 2000-2018 average of 41 per 100 persons. Of these ED visits, 13 percent resulted in hospital admissions, with the remaining 87 percent being “treat-and-release” visits.⁷⁴

The Agency for Healthcare Research and Quality’s Statistical Brief #286, Most Frequent Reasons for ED Visits - 2018, breaks down such visits by condition, thus giving a reference rate per 100 persons for certain conditions.⁷⁵ These annual rates and the estimated increases in ED visits associated with flooding are shown in Table 18. Due to differences in classifications, not every condition with an increase in incidence due to flooding could be captured. Note that injury rates (Injury and Poisoning) should not be combined with those presented in Table 17, as this would likely lead to double-counting the same injuries.



Table 18: Reference ED Visits and Increases Associated with Flooding

Condition	Flood Level (ft)	Reference Treat-and-Release ED Visits (Rate per 100 persons)	Reference Admit ED Visits	Increase in Incidence due to Flooding (Percent)	Notes
Injury and Poisoning	Any	7.5	0.6	50%	Increases by 10% for every day house is flooded; increases by 9% for every foot of depth
Respiratory	Any	4.3	0.7	60%	Increases by 3% for every day house is flooded
Mental, Behavioral, and Neurodevelopmental	<1.5	1.6	0.3	24%	Increases by 7% for every day house is flooded
Mental, Behavioral, and Neurodevelopmental	1.5-3	1.6	0.3	33%	Increases by 7% for every day house is flooded
Mental, Behavioral, and Neurodevelopmental	>3	1.6	0.3	49%	Increases by 7% for every day house is flooded
Skin and Subcutaneous	Any	1.4	0.1	31%	Increases by 7% for every day house is flooded
Pregnancy, Childbirth, and the Puerperium	<1.5	1.0	0.2	5%	N/A
Pregnancy, Childbirth, and the Puerperium	1.5-3	1.0	0.2	35%	N/A
Pregnancy, Childbirth, and the Puerperium	>3	1.0	0.2	31%	N/A
Infectious and Parasitic	Any	0.7	0.6	39%	N/A

The cost of infectious diseases, injuries, and other health impacts can be calculated using the following equation:

Figure 21: Cost of Health Impacts of Floods Equation

Cost of Health Impacts

$$= \sum_{\text{condition}} \left(\frac{PAR}{100} * \text{Reference Treat and Release ED Visits} * \text{Increase in Incidence due to Flooding} * \text{Cost of Treat and Release ED Visit} \right) + \left(\frac{PAR}{100} * \text{Reference Admit ED Visits} * \text{Increase in Incidence due to Flooding} * \text{Cost of Admit ED Visit} \right)$$

This calculation should be used for each RI for the Baseline and Project alternatives. The total costs by RI can be annualized and compared between the Baseline and Project alternatives to calculate project benefits. The annualization process is described in [Section 6.12 Discounting and Annualization](#).

Mental Health

Deteriorations in mental health and/or increased incidences of post-traumatic stress disorder (PTSD) are often results of the stress associated with exposure to a disaster, and may be experienced after evacuating one's home, losing one's home and/or possessions, suffering physical injuries, and/or experiencing the illnesses of family and friends. Mental stress can also be a secondary response to other direct impacts, such as being displaced from home and community, suffering loss of electricity and/or heat for extended periods of time, being unable to receive regular counseling or treatment because of center closure or lack of transportation, or being unable to obtain needed medication. Mental health issues can last for months or years following a flood event, and can lead to sleep disorders, drug/alcohol abuse, an inability to work, and/or a loss of employment productivity driven by the necessity of navigating flood displacement and/or providing care to affected family members.

FEMA has estimated the mental health costs of, and productivity losses from, flooding events per household, which can be used for calculations in a BCA. FEMA has calculated avoided mental stress and anxiety at \$2,443 per person and lost productivity at \$8,736 per worker in 2008 dollars.⁷⁶

The U.S. Census can be used to find the average number of people per housing unit in the study area and the percentage employed per household. The cost of mental health and lost productivity due to flooding can then be calculated using the following equations:

Figure 22: Mental Health and Lost Productivity Costs Equations

$$\text{Mental Health Costs} = (\text{Population Flooded}_{\text{Baseline}} - \text{Population Flooded}_{\text{Project}}) * \text{Mental Health Costs}$$

$$\text{Lost Productivity Costs} = (\text{Workers Flooded}_{\text{Baseline}} - \text{Workers Flooded}_{\text{Project}}) * \text{Lost Productivity}$$

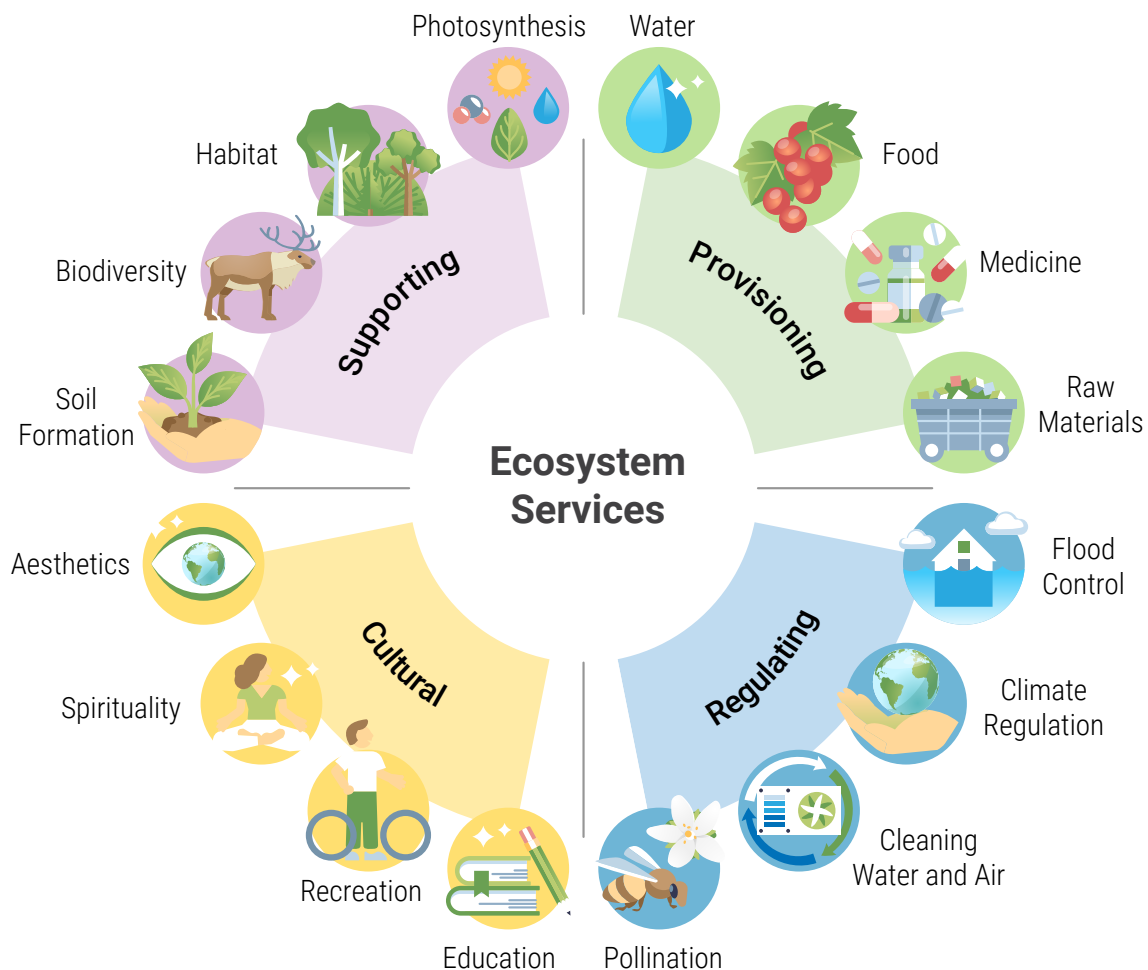
These calculations should be used for each RI. The total costs by RI can be annualized to calculate project benefits. The annualization process is described in [Section 6.12 Discounting and Annualization](#).

6.7 Environmental

Environmental benefits arise from the direct and indirect contributions that ecosystems make to the economic and social well-being of human populations. These include, but are not limited to, improvements to the quality and moderations to the quantity of water; provision of wildlife habitat; mitigation of storms and floods; buffering of pollutants; provision of greater resilience for communities and ecosystems; and support for a wide array of cultural benefits, recreational opportunities, and aesthetic values. The inclusion of environmental benefits in the evaluation of FRM projects thus supports the use of ecosystem-based management, risk reduction, and environmental compliance; and the preservation of the natural and beneficial functions of the floodplain.

The Millennium Ecosystem Assessment (MEA), a major UN-sponsored effort to analyze the impact of human actions on ecosystems and human well-being, has identified four major categories of ecosystem services: provisioning, regulating, cultural and supporting.⁷⁷

Figure 23: Ecosystem Service Categories



- » Provisioning Services
 - » A provisioning service is any type of benefit to people that can be extracted from nature. When people are asked to identify such a service, most think of food – and of course, fruits, vegetables, trees, fish, and livestock are available to us as direct products of ecosystems. However, along with food, other types of provisioning services include drinking water, timber, wood fuel, natural gas, oils, plants that can be made into clothes and other materials, and medicinal extracts.
- » Regulating Services
 - » A regulating service is a benefit provided by an ecosystem process that moderates a natural phenomenon. Regulating services include pollination, decomposition, water purification, erosion and flood control, and carbon storage and climate regulation. Ecosystems provide these and many other basic services that make life possible for people. For instance, plants clean air and filter water, bacteria decompose waste, bees pollinate flowers, and tree roots hold soil in place to prevent erosion. All of these processes work together to make ecosystems clean, sustainable, functional, and resilient to change.
- » Cultural Services
 - » A cultural service is a non-material benefit that contributes to the development and cultural advancement of people, and involves the ways that ecosystems play a role in local, national, and global cultures; the building of knowledge and the spreading of ideas; creativity born from interactions with nature (music, art, architecture); and recreation. As we interact with and alter nature, the natural world in turn alters us. It guides our cultural, intellectual, and social development by being a constant force in our lives. The importance of ecosystems to the human mind can be traced back to the beginning of mankind, when ancient civilizations drew pictures of animals, plants, and weather patterns on cave walls.

- » Supporting Services
 - » The natural world provides so many services that we sometimes overlook its supporting services, which are the most fundamental. Ecosystems themselves, for instance, couldn't be sustained without the consistency of natural supporting services, such as photosynthesis, nutrient cycling, the creation of soils, and water cycling. These processes allow the Earth to sustain basic life, whole ecosystems, and human civilization. Without supporting services, provisional, regulating, and cultural services couldn't exist.

Habitat Valuation

The diverse landscapes in Texas are comprised of many ecosystems that provide vital goods, services, and public benefits. These ecosystem services are the set of functions or products benefitting human well-being; they encompass many life-sustaining products, such as climate regulation, air purification, and pollination.

Many ecosystem services are traditionally considered free to society. For example, everyone enjoys the cleaner air, cleaner water, and flood control provided by healthy forests, rangelands, and wetland ecosystems. Without formal markets, however, the benefits of these services have traditionally been hard to value.⁷⁸ Even still, FEMA has developed economic values for different types of ecosystems, including riparian, wetlands, forests, and marine and estuary.⁷⁹ More information about how these values have been calculated can be found in the [FEMA Ecosystem Service Value Updates, June 2022](#). Ecosystem service values are also shown in Table 19 below.

Table 19: FEMA Ecosystem Service Values (2021 dollars per acre, per year)

Ecosystem Service	Urban Green Open Space	Rural Green Open Space	Riparian	Forest	Costal Wetland	Inland Wetland	Coral Reefs	Shellfish Reefs	Beaches and Dunes
Aesthetic Value	\$7,010	\$7,505	\$767	\$1,477	\$1,648	\$1,303	\$327	-	\$223,840
Air Quality	\$201	-	\$254	\$711	-	-	-	-	-
Biological Control	-	-	\$199	-	-	-	-	-	-
Climate Regulation	\$54	\$77	\$96	\$199	\$125	\$56	-	-	-
Erosion Control	\$78	\$78	\$13,823	\$1,672	-	-	-	-	-
Existence Value	-	-	-	\$7,531	-	-	-	-	-
Flood and Storm Hazard Reduction	\$316	-	\$6,052	\$368	\$1,035	\$1,264	\$3,269	-	-
Food Provisioning	-	-	\$736	-	-	-	\$18	\$1,905	-
Habitat	\$5,890	\$2,021	\$2,547	-	\$2,420	\$1,416	\$2,222	-	-
Pollination	\$350	\$350	-	-	-	-	-	-	-
Recreation/ Tourism	\$1,642	\$601	\$6,215	\$94	\$1,624	\$1,906	\$1,261	\$253	\$76,809
Research & Education	-	-	-	-	-	-	\$23	-	-
Water Filtration	-	-	\$6,239	\$435	\$1,558	\$1,584	-	\$600	-
Water Supply	-	-	\$272	\$103	\$544	\$643	-	-	-
Total	\$15,541	\$10,632	\$37,199	\$12,589	\$8,955	\$8,171	\$7,120	\$2,757	\$300,649

In addition to national values, several Texas state agencies have developed Texas-specific values for certain ecosystem types. In particular, the GLO has published the [Hazard Mitigation Funding Opportunity Approach for Coastal Resilience Projects with Ecosystems Services Methodology](#)⁸⁰, which provides average annual ecosystem service values for oyster reefs, coastal wetlands, coastal bottomland forests, mangroves, coastal prairies, beaches and dunes, and seagrass. These values are shown in Table 20.

Table 20: Texas Ecosystem Values for Coastal Ecosystems (2018 dollars per acre per year)

Ecosystem Type	Value Range
Oyster Reefs	\$46,300-\$90,800
Coastal Wetlands	\$14,900-\$21,600
Coastal Bottomland Forests	\$11,700-\$16,100
Mangroves	\$91,400-\$94,000
Coastal Prairies	\$6,300
Beaches	\$19,400-\$53,000
Dunes	\$5,300-\$38,900
Seagrass	\$26,300

Texas A&M's Natural Resources Institute (NRI) has also developed Texas-specific ecosystem values for what they refer to as "working lands."⁸¹ These privately-owned farms, ranches, and forests produce food and fiber; support rural economies; and provide wildlife habitat, clean air and water, and recreational opportunities. These lands also constitute most of the undeveloped, rural land mass in Texas. Statewide average values for working lands for each ecosystem service and category are shown in Table 21. More information about these values can be found in the [Texas Ecosystem Services: A Statewide Assessment Report](#).

Table 21: Texas Ecosystem Values for Working Lands (2021 dollars per acre per year)

Category	Ecosystem Service	Value
Provisioning	Food and Fiber Production	\$103
Regulating	Erosion Control	\$27
Regulating	Flood Mitigation	\$22
Regulating	Air Quality and Air Pollution Removal	\$19
Regulating	Carbon Storage and Sequestration	\$13
Cultural	Recreation (Consumptive Hunting)	\$9
Cultural	Recreation (Non-Consumptive)	\$12
Supporting	Water Quantity (Replacement)	\$348
Supporting	Water Quantity (Improvement)	\$29
Supporting	Water Quality	\$30
Supporting	Wildlife Habitat and Biodiversity	\$16
Total Ecosystem Services Value		\$629

Ecosystem service benefits can be calculated using the following equation:

Figure 24: Ecosystem Service Benefits Equation

$$Ecosystem\ Service\ Benefits = \sum_{Ecosystem\ Type} Acres\ created\ or\ restored * Value\ per\ acre$$

These are annual benefits and are not based on RI. More information about how to sum and discount annual benefits is shown in [Section 6.12 Discounting and Annualization](#).

Green Infrastructure

GI measures can be used to reduce stormwater runoff by capturing stormwater and allowing it to recharge groundwater supplies or be applied to non-potable uses such as irrigation.

The cost of stormwater management (including the cost of collection, conveyance, and treatment) can be applied to the estimated gallons of stormwater that would be captured annually by an FRM project to calculate the stormwater management benefit.

The impervious nature of development can limit the ability of land to absorb and store stormwater and discharge over time. Consequently, most rainfall becomes surface runoff and immediately goes into drainage infrastructure. Impervious surfaces generate faster rates of runoff than grassed or vegetated areas that slow flows, or open spaces and pervious areas that infiltrate stormwater. High peak runoff rates can create capacity issues in downstream drainage systems and erosion problems in stream channels and can increase pollution in receiving waterbodies (especially in cities with combined sewer systems).

GI measures can be used to reduce stormwater runoff. The number of gallons reduced by each measure would need to be estimated for each project location and site condition. Other benefits of GI can include reduced subsidence and increased air quality.

FEMA has developed proposed values for four types of GI: green roofs, permeable pavement, bioretention, and urban trees.⁸² These values are shown in Table 22. More information about these values can be found in the 2022 document, [FEMA Economic Benefit Values for Green Infrastructure](#).

Table 22: Green Infrastructure Values (2021 dollars per acre per year)

Benefit	Green Roofs (\$/ft ² /year)	Permeable Pavement (\$/ft ² /year)	Bioretention (\$/ft ² /year)	Urban Trees (\$/tree/year)
Building energy cost savings	\$0.05	-	-	\$17.05
Carbon sequestration and avoided emissions	\$0.01	\$0.003	\$0.02	\$6.33
Drought risk reduction	-	\$0.13	\$0.52	\$5.53
Habitat	\$0.05	-	\$0.11	\$40.18
Heat risk reduction	-	-	-	\$910.28
Property value improvement	\$0.19	-	\$0.40	\$53.15
Removal of air pollutants	\$0.001	-	\$0.004	\$2.50
Stormwater volume and quality	\$0.09	\$0.51	\$1.80	\$20.17
Total (\$/ft²/year)	\$0.40	\$0.64	\$2.84	\$1,055.19
Total (\$/acre/year)	\$17,617	\$27,949	\$123,599	N/A

GI service benefits can be calculated using the following equation:

Figure 25: Green Infrastructure Benefits Equation

$$\text{Green Infrastructure Benefits} = \sum_{GI \text{ Measure}} \text{Acres created or restored} * \text{Value per acre}$$

These are annual benefits and are not based on RI. More information about how to sum and discount annual benefits is shown in [Section 6.12 Discounting and Annualization](#).

Water Quality and Quantity

Some FRM projects may also have impacts on Texas water supplies, such as a reservoir that can capture and store flood water for use when rivers are low. A reliable water supply system is crucial to the effective functioning of the economy. Although the importance of water is evident, estimating its value is a complex process. The most widely accepted method for estimating water supply benefits is to multiply the annual yield by the average price of water. There are several factors that influence the price of water, including but not limited to, location, type (surface or groundwater), quality and reliability, and the anticipated use of the water. Examples of groundwater pricing in Texas range from \$400 to over \$3,000 per acre-foot,^{83,84} while examples of surface water include the Lower Colorado River Authority at \$155 per acre-foot (\$165 proposed),⁸⁵ the Brazos River Authority at \$93.50 per acre-foot⁸⁶, and the Lower Neches Valley Authority at \$37.50 per acre-foot⁸⁷. These values can vary significantly within the state. Given the differences in Texas water supply needs, individual projects should use local water costs for the value of water supply, with appropriate documentation.



Water supply benefits can be calculated using the following equation:

Figure 26: Water Supply Benefits Equation

$$\text{Water Supply Benefits} = \text{Increase in annual water supply} * \text{Price per ac ft}$$

These are annual benefits and are not based on RI. They occur every year of the analysis period, regardless of the likelihood of a flood event occurring. More information about how to sum and discount annual benefits is shown in [Section 6.12 Discounting and Annualization](#).

6.8 Recreation

Some flood control projects, such as reservoirs and wetland restoration projects, can also become popular destinations for a wide variety of recreational activities, including fishing, boating, camping, swimming, water sports, and wildlife observation. There are several methods for estimating these benefits, with the simplest being the unit-day-value (UDV) method. The UDV method for estimating recreation benefits relies on expert or informed opinion and judgment to approximate the average willingness of users to pay for recreational resources.

The UDV method is based upon assigning a certain number of points to each of 5 criteria: (1) recreation experience, (2) availability of opportunity, (3) carrying capacity, (4) accessibility, and (5) environmental quality. The evaluator assigns a certain number of points to each of these criteria based upon the judgment factors listed in Table 23; the total number of points is then converted to a UDV dollar amount using the point assignment method. This UDV dollar amount is then multiplied by the number of visitor-days projected for the project. The difference in the total value of recreation between the Baseline and Project alternatives represents the recreation benefits of the project.

The criteria, judgment factors, and point values for general recreation are shown in Table 23. Judgment factors and point values for specialized recreation can be found in the latest [USACE Economic Guidance Memorandum](#).

Table 23: Criteria and Judgment Factors for General Recreation

Criteria	Judgment Factors	Judgment Factors	Judgment Factors	Judgment Factors	Judgment Factors
Recreation Experience	Two general activities	Several general activities	Several general activities; one high quality	Several general activities; more than one high quality	Numerous high quality value activities; some general activities
Point Value	0-4	5-10	11-16	17-23	24-30
Availability of Opportunity	Several within 1 hr. travel time; a few within 30 min. travel time	Several within 1 hr.; none within 30 min.	One or two within 1 hr.; none within 45 min.	None within 1 hr.	None within 2 hr.
Point Value	0-3	4-6	7-10	11-14	15-18
Carrying Capacity	Minimum facility for development for public health and safety	Basic facility to conduct activity(ies)	Adequate facilities to conduct without deterioration of the resource or activity experience	Optimum facilities to conduct activity at potential site	Ultimate facilities to achieve intent of selected alternative
Point Value	0-2	3-5	6-8	9-11	12-14
Accessibility	Limited access by any means to site or within site	Fair access, poor quality roads to site; limited access within site	Fair access, fair road to site; fair access, good roads within site	Good access, good roads to site; fair access, good roads within site	Good access, high standard road to site; good access within site
Point Value	0-3	4-6	7-10	11-14	15-18
Environmental Quality	Low aesthetic factors that significantly lower quality	Average aesthetic quality; factors exist that lower quality to minor degree	Above average aesthetic quality; any limiting factors can be reasonably rectified	High aesthetic quality; no factors exist that lower quality	Outstanding aesthetic quality; no factors exist that lower quality
Point Value	0-2	3-6	7-10	11-15	16-20

Source: USACE. Memorandum for Planning Community of Practice. Economic Guidance Memorandum 25-04, Unit Day Values for Recreation for Fiscal Year 2025. 18 February 2025. <https://planning.ercd.dren.mil/toolbox/library/EGMs/EGM25-04.pdf>

The USACE provides updated UDVs for recreation each fiscal year; the most updated values can be found in the [Planner's Library Economic Guidance Memoranda](#) list.

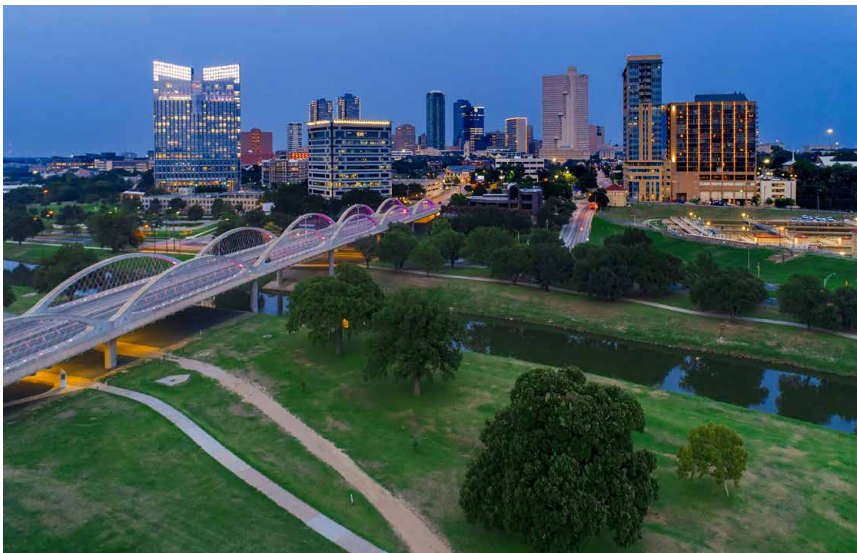
The UDV methodology is incorporated into the [Flood BCA Calculator](#). To estimate benefits, project applicants need to determine the number of annual visitors to a recreation area in both Baseline and Project alternatives, the types of recreational activities in which they participate, and how the project will impact the quality of their experience.

The value of recreation can be calculated using the following equation:

Figure 27: Unit Day Value Recreation Benefits Equation

$$\text{Recreation Value} = \text{Annual visitors} * \text{UDV}$$

Recreation values should be calculated for the Baseline and Project alternatives. These are annual benefits and are not based on RI. More information about how to sum and discount annual benefits is shown in [Section 6.12 Discounting and Annualization](#).



6.9 Large scale regional or state economic activity impacts

In addition to the direct damages discussed in this BCA Guidance Document, floods also cause longer-term economic impacts, such as impacts to business employment and the number of establishments in different sectors of the economy.

Some of the most valuable real estate in the nation is in areas that have a high risk of flooding. For instance, many industrial facilities are built near rivers and harbors for easy access to waterborne transportation. Likewise, coastal communities are highly desirable as residential locations and tourist destinations and offer many recreational activities. FRM projects reduce the risk of flood damage to such resources, as well as to vital infrastructure such as energy grids and transportation networks, thus protecting the economic activity generated by these facilities.

Major flooding events have both short-term and long-term impacts that may vary depending on existing infrastructure, community planning, and recovery efforts. Major or repeated flood impacts are likely greater than initially observed, direct losses within a flooded area due to longer-term changes in population migration and the allocation of public and private resources.

Flooding can also destroy or impede the factors of production, both labor-related and in terms of physical capital. The direct impacts captured elsewhere can cause business interruptions and trigger additional indirect impacts to local, regional, and even national or international supply chains. If lost capital is not replaced, the level of production will be permanently reduced. Industries dependent on larger labor pools, such as manufacturing or the service sector, are more flexible in terms of relocating due to major or repeated flooding event(s), relative to industries more dependent on natural resources or amenities in the affected region. If a local manufacturing or large service-related firm were to relocate after suffering significant flood-related losses, however, the result would be a permanent reduction in contributions made by that firm to the local economy (e.g., to employment, labor income, and/or gross regional domestic product).

Conversely, the likelihood of a permanent loss of agriculture-related activity resulting from flooding may be relatively low in regions dominated by agriculture. However, agricultural land may have to be cleaned and restored, which may result in post-flooding economic losses due to delays in production activity.⁸⁸

Additionally, new or improved infrastructure that enhances a community can reshape the economic geography of a region. The economic theory of “agglomeration” suggests that firms and households can enjoy positive benefit spillovers from the spatial concentration of economic activity. These benefits may stem from access to larger and more specialized labor pools, availability of a wider array of firms and services, more efficient use of common resources and facilities (such as those that provide transport, communications, or utilities), and/or improved access to hospitals and schools.⁸⁹

There is the potential for agglomeration benefits resulting from projects that impact the size of the labor market and/or the future concentration of economic activity in a location, but the scale, type, and overall potential for such benefits is highly context- and project-specific, and thus there is not currently guidance on how such impacts should be quantified. At this time, any agglomeration-related benefits that might be expected to accrue from a project should be discussed in qualitative terms, while carefully laying out the expected linkages between the project and those potential outcomes. For large scale projects that may produce a concentration of economic activity or prevent widespread losses, it may be appropriate to conduct an EIA in addition to a BCA to help guide decision making.

6.10 Residual Value

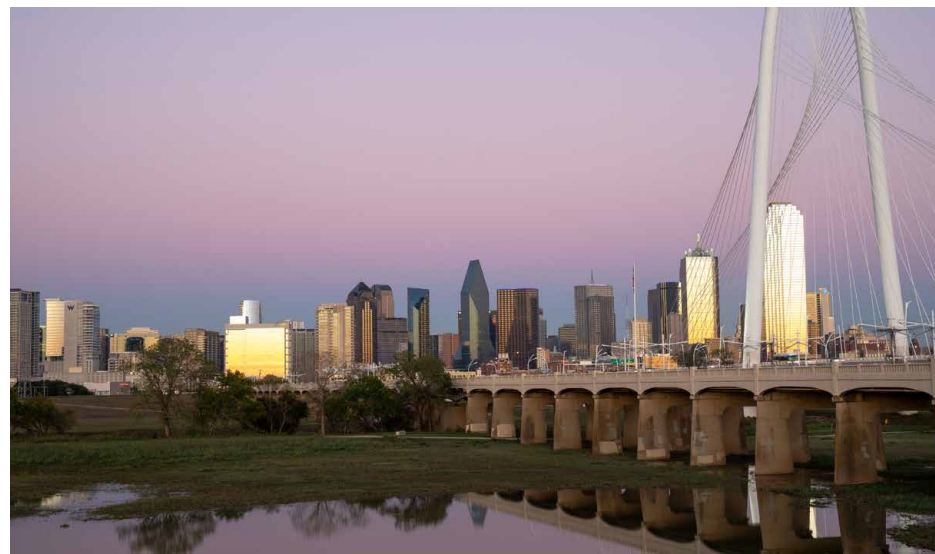
Sometimes the useful life of an asset exceeds the reasonable period of analysis used in the BCA. In these cases, the remaining value at the end of the analysis period can be calculated based on the useful life and the installation date of the asset (typically using straight-line depreciation), and discounted to the present. BEA provides service lives for a variety of asset types, including governmental, nonresidential structures (e.g., highways and streets, drainage systems), which generally have useful lives of 45-60 years. FEMA standards for useful life values and acceptable limits can be found in [Appendix D of the FEMA BCA Reference Guide](#). Useful lives can also come from engineering estimates.

Residual value can be calculated using the following equation:

Figure 28: Infrastructure Residual Value Equation

$$\text{Residual Value} = \text{Beginning Value} * \frac{(\text{Asset Useful Life} - \text{Length of Analysis Period})}{\text{Asset Useful Life}}$$

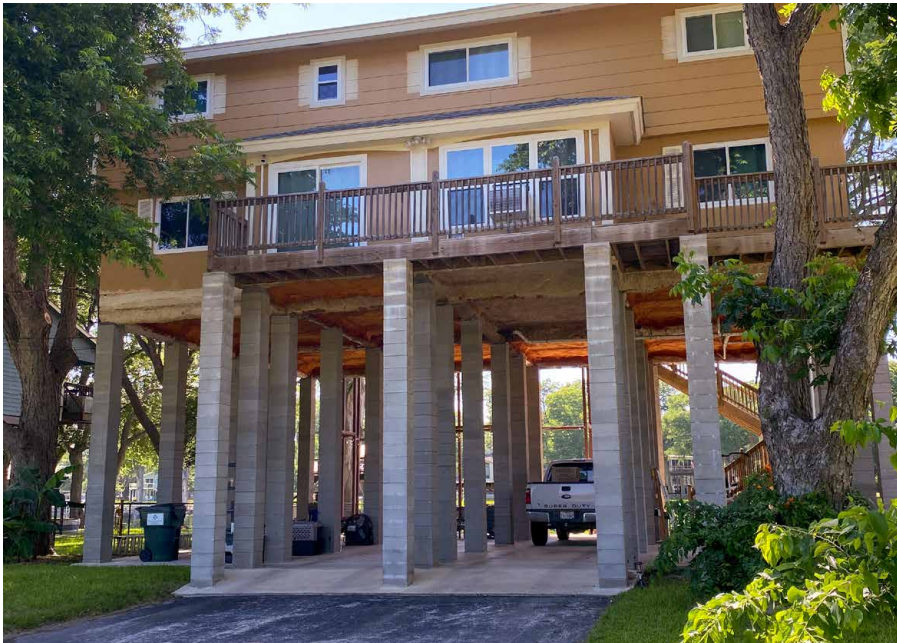
These are one-time benefits that occur in the last year of the analysis period.



6.11 Acquisitions and Elevations

Two common mitigation activities are acquisitions and elevations. These are sometimes referred to as “non-structural” alternatives because they do not involve the construction of new infrastructure such as levees or drainage systems. These projects reduce the consequences of flooding but do not reduce the water levels or the extent of flooding.

Due to the frequency that these types of projects are proposed and implemented throughout the country, FEMA has developed “pre-calculated” benefits for acquisitions and elevations.⁹⁰ These values have been calculated based on research and statistical analysis or computer modeling of mitigation projects. As of March 2025, acquisition projects in the SFHA or RL/SRL acquisition projects outside of the SFHA that cost less than \$775,411 per structure are assumed to be cost-effective without a BCA. Elevation projects in the SFHA that cost less than \$355,522 per structure are assumed to be cost-effective without a BCA.⁹¹



For projects that do not meet those criteria or are requesting funding from a program that does not recognize these pre-calculated benefits, a BCA should be conducted using the methodologies described in the previous sections. While WSEs will be the same in both the Baseline and Project conditions, structure elevations increase the FFE, resulting in less damages and fewer impacts. Structure acquisitions remove the structure altogether, so Project structure and content damages and displacement are zero. Note that acquisitions are generally the only project type for which it is commonly accepted that there are no residual damages following Project implementation.

The primary benefits for non-structural projects are expected to be structure and content damages/displacement avoided (**Section 6.1 Structure and content damages** and **Section 6.2 Loss of Function**); health and safety benefits are also appropriate for both elevations and acquisitions (**Section 6.6 Health & Safety**). Acquisitions may also provide ecosystem service benefits (**Section 6.7 Environment & Water Quality and Quantity**), usually resulting in green open space.

6.12 Discounting and Annualization

Once all of the benefits are calculated for each relevant benefit category, they must be discounted to the present to compare to the costs and calculate a BCR. Each year of benefits is discounted to the present, and the discounted benefits over the whole analysis period are summed to calculate the present value of the benefit stream. For probabilistic events based on RI (e.g., damages avoided), the damages for each RI must first be annualized to determine the EAD prior to being discounted.

Benefits that are based on avoided damages by RI are calculated using the probability-weighted average damages. This can be done by integrating over the probability domain (cumulative distribution function) or can be reasonably approximated using discrete trapezoidal areas under the damage curve. For an interval of exceedance probability, the area under the curve can be calculated as a trapezoid where the top of the trapezoid is a straight line between the two function values. This calculation is repeated on intervals

of exceedance probability between 0 and 1. The areas of these trapezoids are summed to calculate the EAD.

It is not recommended that most practitioners conduct this calculation themselves. The FEMA BCA Toolkit v6.0 Professional Expected Damages module is a good tool to use to calculate the present value of benefits based on damages from multiple RIs. The FEMA BCA Toolkit provides both annualized damages (the user must click on the “View Annualized Results” button) and the discounted total benefits (“Total Mitigation Project Benefits”).

An example of the expected annual damage from multiple RIs is shown in Table 24.

Table 24: Expected Annual Damage from Multiple Recurrence Intervals

Recurrence Interval	Probability	Event Damages	Annual Damages
10-year	10%	\$20,000	\$2,683
25-year	4%	\$100,000	\$9,487
100-year	1%	\$1,000,000	\$25,298
500-year	0.2%	\$10,000,000	\$19,999
Total (Expected Annual Damage)			\$57,467

The difference between the EAD in the Baseline and the Project conditions are the annual benefits.

Annualized damage reduction benefits and annual benefits that occur in each year of the analysis period regardless of the likelihood of a storm event (e.g., ecosystem benefits, recreation benefits) can then be discounted to the present to compare with project costs. Discounting should be performed using the pre-determined discount rate as described in [Section 2.3 Inflation and Discounting](#). Benefits are discounted using the following formula:

Figure 29: Discounting Equation

$$\text{Discounted Benefits} = \frac{\text{Benefits}}{(1 + \text{Discount Rate})^{(\text{Calendar Year} - \text{Discount Year})}}$$

The Present Value of the benefits are the sum of the discounted benefits calculated for each year.

An example using 20 years of benefits (2026-2045), discounted to the year 2024 using a 3.1 percent discount rate, is shown in Table 25.

Table 25: Annual Benefits Discounting Example

Calendar Year	Project Year	Benefits	Discounted Benefits
2026	1	\$1,000,000	\$940,768
2027	2	\$1,000,000	\$912,481
2028	3	\$1,000,000	\$885,045
2029	4	\$1,000,000	\$858,434
2030	5	\$1,000,000	\$832,622
2031	6	\$1,000,000	\$807,587
2032	7	\$1,000,000	\$783,305
2033	8	\$1,000,000	\$759,752
2034	9	\$1,000,000	\$736,908
2035	10	\$1,000,000	\$714,751
2036	11	\$1,000,000	\$693,260
2037	12	\$1,000,000	\$672,415
2038	13	\$1,000,000	\$652,197
2039	14	\$1,000,000	\$632,587
2040	15	\$1,000,000	\$613,566
2041	16	\$1,000,000	\$595,117
2042	17	\$1,000,000	\$577,224
2043	18	\$1,000,000	\$559,868
2044	19	\$1,000,000	\$543,034
2045	20	\$1,000,000	\$526,706
Total			\$14,297,626



7.0 Community Vulnerability

Multiple decisions within the BCA process implicitly or explicitly incorporate value judgments: scoping and methodology decisions about the relevant policy options, which costs and impacts to measure and how, how to aggregate costs and benefits for different people and organizations, how to value future costs and effects, and many others. This Guidance Document and the associated **TWDB Flood BCA Calculator** aim to make the BCA process more equitable in several ways. One way is through the development of the TWDB Flood BCA Calculator. Accurate models and the necessary skills and data to use them are not equally available, but the Flood BCA Calculator is designed to be relatively easy to use without requiring specialized computer programs or statistical knowledge and incorporate default data while allowing users to adjust those defaults as appropriate. Another is through attempting to quantify additional benefits that

society widely agrees are important for community well-being, such as health and wellness, recreation, and ecosystem services. Members of a society naturally derive value from elements of life that are not traditionally monetizable (e.g., recreation), so by not accounting for these harder-to-quantify benefits, BCAs run the risk of undervaluing many projects, policies, and programs.⁹² While these factors were once considered difficult to measure and apply economic value to, advances have been made in establishing commonly-understood frameworks for their quantification.⁹³

As explained previously, BCA is a tool that allows practitioners to evaluate, in monetary terms, a project, policy, or program's value to all members of society. However, not all members of society will experience the benefits and costs in the same manner.

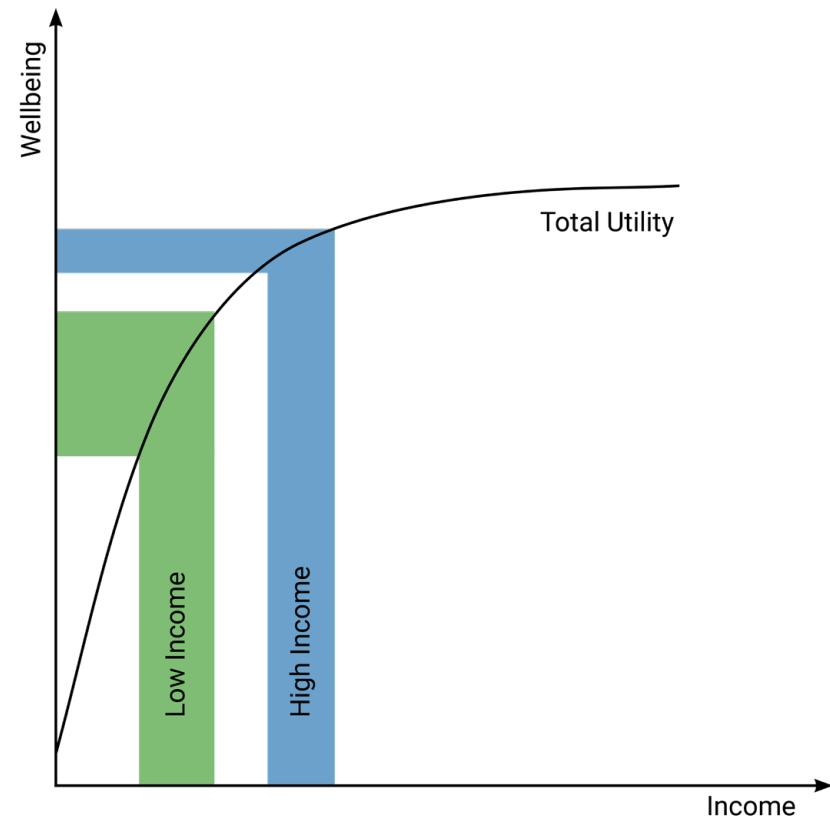
A criticism of standard BCA methodology is that structure value losses tend to be one of the most dominant benefit categories for hazard mitigation studies, thus inherently favoring more dense areas and those with higher structure values (see [Section 4.2 Emphasis on Property Values](#)). Areas with high structure values tend to, by nature, be more expensive than average to live in, and thus higher-income populations are typically associated with higher value properties. Projects that provide benefits for more, higher-value structures, and therefore higher-income households, tend to have higher BCRs, and thus perform more competitively than those that benefit lower-income areas.⁹⁴ Higher-income households, however, are better equipped to recover from a disaster when compared to lower-income households, suggesting that project benefits are not experienced equally by everyone.⁹⁵ One way to overcome this criticism is through the application of income weights.



7.1 Income Weights

It is useful here to consider the key economic principle of “marginal utility of the dollar,” which considers the value of one additional dollar transferred to an individual or a specific population. This principle finds that the marginal utility of the addition or preservation of a dollar in a low-income household’s wallet is higher than the marginal utility of a dollar to a higher-income household. This is demonstrated in Figure 30.

Figure 30: Diminishing Marginal Utility of Income



Source: Nelson, Nanette, and Andrea Bohmholdt. *Benefit-Cost Analysis and Consideration of Distributional Effects and Social Equity*. Mitre. 2021.

Given this, a BCA primarily based on avoided structural/content damages may inherently undervalue projects that would provide comparatively higher benefits to low-income households.

Income distributional weighting is one method for evaluating social differences in project, program, or policy evaluation; and for uncovering how the utility of public investments or policies may differ between income groups and geographies. Income-based weights are the most common. The values of the weights are derived from the marginal utility that different income levels receive from an increase in, or preservation of, income. The relationship between income and utility is logarithmic, or diminishing, with the utility of each additional dollar decreasing as incomes rise.⁹⁶ Research about income-weighted BCA confirms that the value of weighted BCA is most pronounced with projects or policies that target lower-income, often rural, populations.^{97,98,99} For these projects or policies, displaying income-weighted values alongside unweighted values allows for simplified identification of the trade-offs between the monetary efficiency of the conventional BCA and the distributional benefits of the weighted BCA, which provides an important data point for understanding the scope of expected impact.

In 2024 FEMA added distributional weights for Building Replacement Values to the [FEMA BCA Toolkit v6.0](#).

Methodology

The below methodology is one approach for developing and applying income-based weights. The primary steps of the analysis include:

1. Develop the weights:
 - a. Determine the median income of the affected population, using the smallest relevant geographic boundary, such as census tract or block group, and the median income of the project or program's tax base. For statewide planning programs such as the Texas State Flood Plan or FIF, the tax base would be comprised of the entire state's residents and households. Household incomes for the project area can be sourced from the U.S. Census.
 - b. Calculate the utility of the median income of the affected population and the utility of the median income of the state as a whole using the following equation:

Figure 31: Utility of Income Equation

$$U(Y) = \frac{Y^{(1-\gamma)}}{(1-\gamma)}$$

Where Y is the median income and γ is the elasticity of marginal utility.

Recent analysis of the elasticity of marginal utility estimates that its value in the United States ranges from 1.15 to 1.40. [OMB Circular A-94](#) recommends a value of 1.4.^{100, 101, 102}

- c. Calculate the utility of the median income plus one dollar for the affected population and for the state as a whole, using the same formula as above.¹⁰³
- d. The marginal utility of a dollar for each population is the difference between the utility of the median income (step b) and the utility of the median income plus one dollar (step c).
- e. Calculate the weight for the affected population by dividing the marginal utility of one dollar for the affected population by the marginal utility of one dollar for the state.

2. Apply weight to the cost-avoided benefits that result in an out-of-pocket expense for the impacted population. Examples include:
 - a. Structure and content loss to privately owned buildings
 - b. Evacuation costs
 - c. Displacement and disruption costs
 - d. Direct wage loss
3. Calculate the BCR using the total weighted benefits, the benefits that do not receive weights (or are not considered direct, tangible benefits), and the project costs. The final formula is the following:

Figure 32: Income Weighted BCR

$$\text{Income Weighted BCR} = \frac{(\text{Income Weights} * \text{Direct Benefits}) + \text{Other Benefits}}{\text{Costs}}$$

The final output is referred to as the income-weighted BCR, which can then be compared with a standard BCR to understand if a program or project may provide benefits that will have greater utility to lower-income households. If the BCR is greater than 1, then the project's benefits outweigh its costs, and it is cost-effective.





CASE STUDY: Brooklyn Bridge Montgomery Coastal Resilience (BMCR) BCA Report

The Brooklyn Bridge Montgomery Coastal Resilience (BMCR) BCA Report presents both an income-weighted BCR and a standard BCR, side-by-side. The report evaluates a project that includes floodwalls, roller gates, and deployable (“flip-up”) flood barriers designed to protect a 0.8-mile stretch of Lower Manhattan in NYC (including its critical infrastructure, businesses, and residents) from a 100-year storm event in 2050.¹⁰⁴ This project is part of a broader coastal resiliency program to reduce flood risk due to coastal storms and sea level rise in Lower Manhattan. The BMCR project area is unique because it has a high density of public housing and a high density of households earning below the Median Household Income for New York City and New York State, particularly when compared to the other projects that are part of the Lower Manhattan Coastal Resilience program.

Given these conditions, the BMCR’s BCA report included an income-weighted BCR to illustrate the value that the project would provide to households, particularly those with lower incomes. Weights were applied to benefits that were associated with direct out-of-pocket expenses, including structure loss to privately owned buildings, content loss, relocation costs, rental costs, direct wage loss, and shelter costs. While the standard BCRs for the BMCR project were 1.7 and 1.1 (using 3 percent and 7 percent discount rates, respectively), the weighted BCA returned BCRs of 3.2 and 2.0. This is because the BMCR project mitigates damages and losses specifically in an area with households with a higher-than-average marginal utility of a dollar, and thus the weighted BCR is better able to capture how the benefits of the project affect lower-income residents in the project area.

Table 26: BMCR Results (Millions of Dollars, 2020 Price Level)

Discount Rate	Total Costs	Standard Benefits	Weighted Benefits	Standard BCR	Weighted BCR
7 percent	\$399.50	\$455.10	\$814.80	1.1	2.0
3 percent	\$510.00	\$869.40	\$1,621.80	1.7	3.2

Income Weights Discussion

While BCAs cannot capture all conceivable impacts, advances in methodology allow the inclusion of more comprehensive benefits depending on the needs of a project. Income weighting presents a unique opportunity to consider the distributional outcomes of a project on a particular community. One of the benefits of the weighted BCA is that it augments an existing tool that is widely used among practitioners. Most other options (such as Social Vulnerability Indices [SVIs] or multi-criteria analyses¹⁰⁵) sit outside of the BCA, and their value, or how to consider them in a project evaluation process, is inconsistent across agencies.¹⁰⁶

Some economists argue that direct wealth transfers towards an impacted population may be a more effective use of resources,¹⁰⁷ and funds that directly address damages suffered by victims after a catastrophe are a more expedient, and thus better use, of funding. However, this approach assumes that those direct wealth transfers are available; it also further entrenches structural disadvantages, as the lower BCRs of projects that protect vulnerable, often rural, communities will lead to less investment in their areas in the long term. Perhaps more importantly, post-disaster wealth transfers condemns more vulnerable communities to more frequently suffer the initial harms of catastrophe, which may be preventable.

If the BCR of a project is one data point among many to be used when making funding decisions, presenting both the standard BCR and the income-weighted BCR as complementary figures can provide more information to help decision makers prioritize and select specific projects.



8.0 Sensitivity

Prospective benefit-cost analyses of FRM infrastructure investments are subject to varying levels of uncertainty attributable to the use of preliminary cost estimates, difficulty of modeling/projecting future flood levels, large variations in the structure and content characteristics of the project area, and changing conditions over time. Even a very detailed BCA with significant data collection efforts will use assumptions and default values for certain parameters and decisions that are made about the analysis with varying degrees of subjectivity. BCA results may vary based on funding agency decisions such as discount rate and monetization policies. Other decisions or assumptions that are made by the analyst can also have large impacts on the resulting BCR.

Some inputs are difficult to measure, but in principle could be measured. This may include structure values or FFEs, which are measurable but often not readily available. Some data requirements

cannot be measured, but must be estimated, such as future land uses or traffic levels. Finally, some inputs are subjective choices, for either the funding agency or the applicant, such as the discount rate or the methodology used to monetize non-dollar denominated benefits that also have a large impact on findings. It is important for the BCA analyst to consider assumptions or other subjective decisions and the order-of-magnitude impact that they can have on the final benefit number and how sensitive a FRM BCA is to certain factors within the analysis.

As discussed in [Section 1.0 Introduction](#), one purpose of conducting a BCA is to promote efficient resource allocation through well-informed, transparent decision-making. The more detailed data that is available and used for the BCA, the lower the risk of making poor or incorrect funding decisions. Therefore, although the [TWDB Flood BCA Calculator v2.0](#) includes default data, as the planning progresses

from conceptual to detailed design, BCA analysts should try to use the most accurate data available for their project. The amount of effort that goes into addressing the risk and uncertainty of an analysis should be commensurate with the level of risk (cost) of the project, and whether reducing the uncertainty has the potential to change the recommendation for the project.

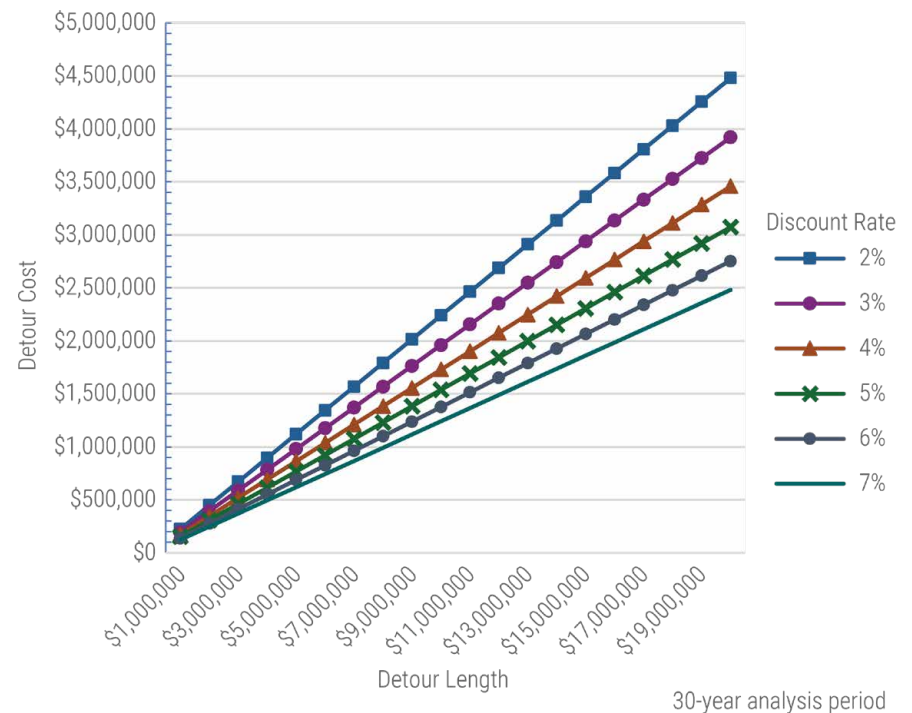
Some subjective and objective factors that impact the benefits are the discount rate, the frequency and severity of flooding that is being mitigated, the values and elevations of the impacted structures, the size of the impacted population, and the volume of traffic and required detours on a flooded roadway/low water crossing. It is also important to remember that benefits are only half of the BCR, and the final BCR is highly sensitive to the costs of the proposed mitigation action.

An analyst will reasonably be able to modify only some of these factors in a sensitivity analysis for a particular project. For example, the discount rate is usually set by the agency that is funding the project, and the volume of traffic on a roadway can be objectively measured. Project costs, effectiveness, and the benefiting area (structures and associated populations) may only be modified by working closely with the engineers designing the project, and changes to these factors could drastically change the project and whether it meets the original purpose and need. However, the following sections of this Guidance Document present order-of-magnitude changes for a variety of factors, many of which would not be changed in a typical sensitivity analysis. The purpose of presenting these factors is to show why projects with similar designs or costs may result in differing BCRs depending on the frequency of existing flooding, the effectiveness of the project at preventing that flooding, and the characteristics of the building stock and population of the area.

8.1 Discount Rate and Analysis Period

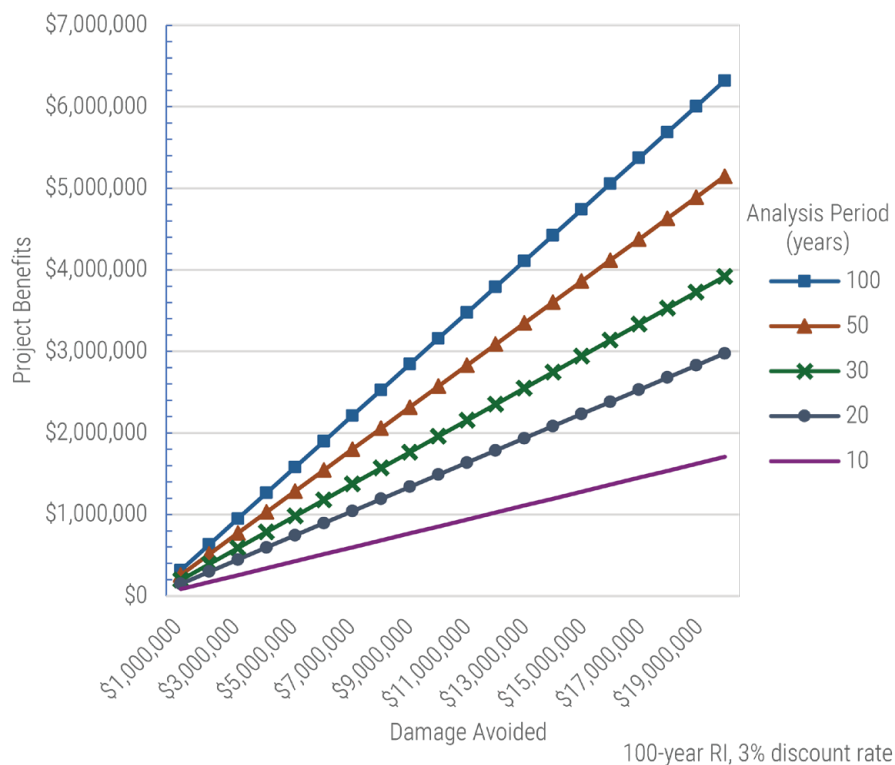
As discussed in [Section 4.3](#), discount rates are subjective policy decisions that reflect competing social, economic, and political priorities. The higher the discount rate, the lower the present value of future benefits. For typical investments, with costs concentrated in early periods and benefits following in later periods, raising the discount rate will reduce the net present value. The relationship between damages avoided for a 100-year RI and project benefits at six different discount rates is shown in Figure 33. This figure shows that a mitigation project would have to prevent approximately \$11 million in 100-year damages to justify a \$2 million project cost using a 3 percent discount rate but would have to prevent approximately \$17 million in 100-year damages to justify that same \$2 million project cost using a 7 percent discount rate.

Figure 33: Project Benefits by Damages Avoided and Discount Rate, 100-year RI



The length of the analysis period can also have an impact on total benefits, although due to discounting, this benefit diminishes as the timespans increase. Figure 34 compares the project benefits based on 100-year damages avoided for six analysis periods from 10 to 100 years. The most commonly-used analysis periods are 30- or 50- years, but even within that span, lengthening the analysis period from 30 to 50 can add millions to the project benefits. It is obviously important to remember that the analysis period should be based on the actual lifespan of the project under the maintenance conditions that are factored into the annual maintenance costs used for the BCA. FEMA standards for useful life values and acceptable limits can be found in [Appendix D of the FEMA BCA Reference Guide](#). Very long or very short periods should generally only be used under specific, justifiable conditions.

Figure 34: Project Benefits by 100-year Damages Avoided and Analysis Period (years)



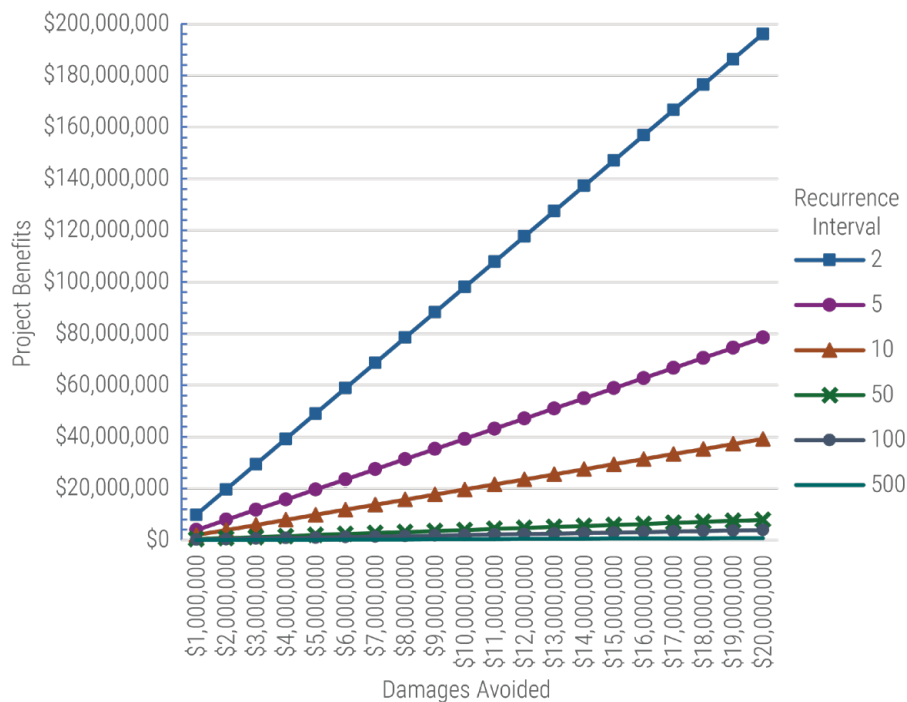
8.2 Project Conditions

While the discount rate and analysis period can be subjective decisions when conducting a BCA, made by either the analyst or the funding agency, other conditions that can have a large impact on whether or not a project is cost-effective are more objective and project-specific.

One factor with a large impact on benefit estimation is the frequency of flooding that is being mitigated. The more frequently damages occur in the Baseline or Before Mitigation condition, the higher the benefits of reducing those damages will be. This can be seen in Figure 35, which compares the damages avoided to the project benefits for various commonly-used RIs. For example, a \$20 million project would have to prevent over \$100 million in damages in a 100-year storm to be cost-effective, but only \$5 million in damages from a 5-year storm, assuming for both a 3 percent discount rate and 30-year analysis period. (In general, the most frequent event in which damages occur should be used in the BCA. The TWDB State Flood Plan and FIF also require modeling of the 100-year event. The TWDB Flood BCA Calculator v2.0 allows users to enter up to three RIs; future versions will increase the number of RIs.)

While determining the extent of existing flooding and the effectiveness of the proposed project to prevent that flooding is generally outside the realm of a BCA, an analyst should use the most-frequent RI that flooding occurs to increase the likelihood of cost-effectiveness. Additionally, the more RIs that are included in the analysis, the more accurate and refined will be the results.

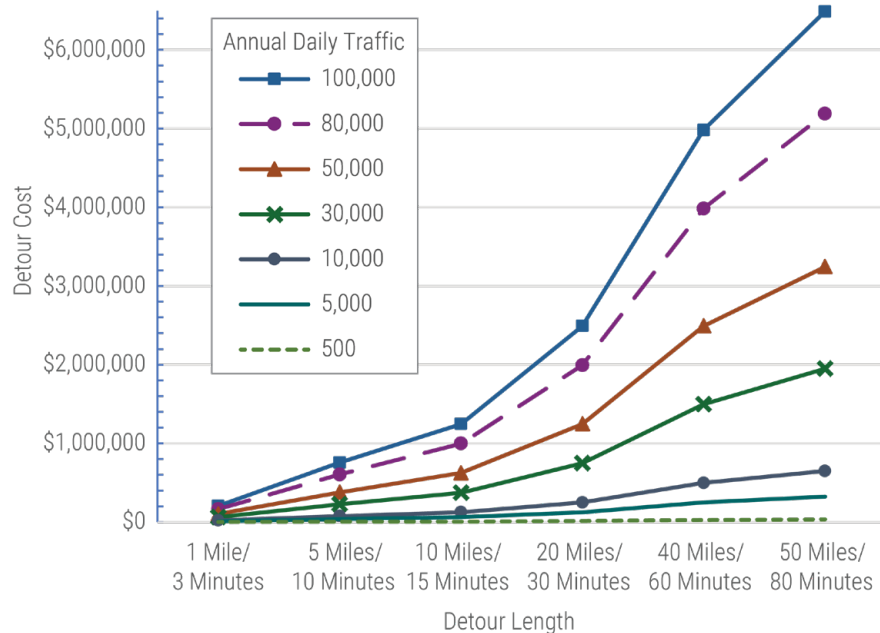
Figure 35: Benefits by Damages Avoided and Recurrence Interval



3% discount rate, 30-year analysis period

The characteristics of the proposed project area will also obviously have a major impact on the project benefits. For example, when accounting for detour costs for flooded roadways, short detours on very busy roads can produce more benefits than even very long detours on less-traveled roads. As Figure 36 and Table 24 show, a 1-mile, 3-minute detour on a busy road such as an interstate with an AADT of 80,000 costs more than a 20-mile, 30-minute detour on a collector or arterial street with an AADT of only 5,000, and therefore will be able to justify a higher cost to avoid/mitigate.

Figure 36: Detour Costs by Traffic Level and Detour Length



3% discount rate, 30-year analysis period

Realistically, even short-distance detours on heavily trafficked roads will have longer detour times than those presented here and will likely impact traffic on other, non-flooded roadways, further increasing detour costs and project benefits. Therefore, it may be reasonable to incur the costs of conducting detailed traffic modeling for projects that will prevent flooding on roadways with high AADTs.

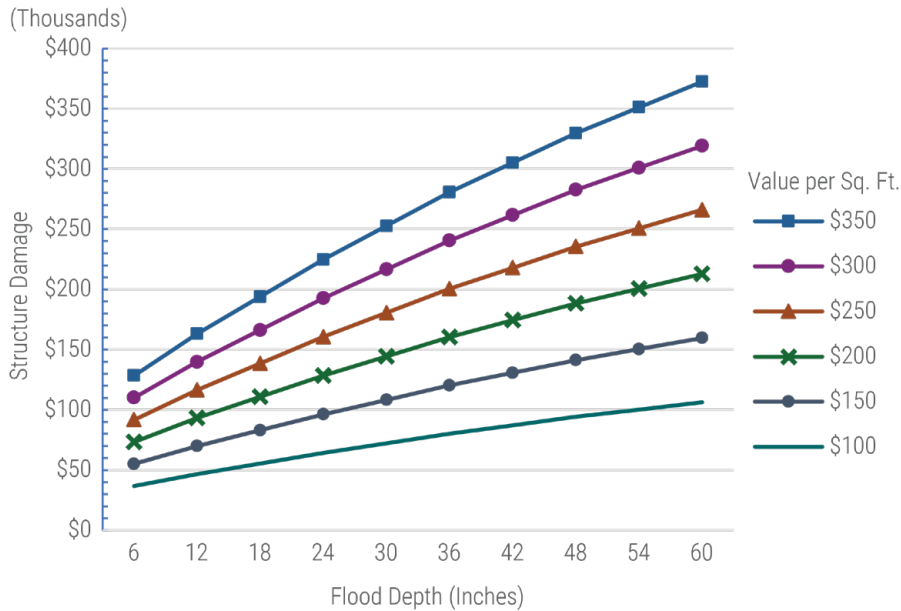
Table 27: Detour Costs by Traffic Level and Detour Length

Roadway Type	AADT	1 Mile/ 3 Minutes	5 Miles/ 10 Minutes	10 Miles/ 15 Minutes	20 Miles/ 30 Minutes	40 Miles/ 60 Minutes	50 Miles/ 80 Minutes
Rural/Local	500	\$1,000	\$4,000	\$6,000	\$12,000	\$25,000	\$32,000
Collector	5,000	\$10,000	\$38,000	\$62,000	\$124,000	\$249,000	\$324,000
Arterial	10,000	\$20,000	\$75,000	\$124,000	\$249,000	\$498,000	\$649,000
Primary Arterial	30,000	\$61,000	\$226,000	\$373,000	\$747,000	\$1,494,000	\$1,946,000
Interstate	50,000	\$101,000	\$377,000	\$622,000	\$1,245,000	\$2,490,000	\$3,243,000
Interstate	80,000	\$162,000	\$603,000	\$996,000	\$1,992,000	\$3,984,000	\$5,189,000
Interstate	100,000	\$203,000	\$753,000	\$1,245,000	\$2,490,000	\$4,980,000	\$6,486,000

3 percent discount rate, 30-year analysis period

As discussed in **Section 3.2**, home size and value have the potential to introduce significant variations into a BCA, with neighborhoods with larger, more expensive homes generally producing more damages, and therefore more benefits when mitigated, compared to more modest areas. Differences can also occur from the use of different types of home value evaluations (market, assessed, replacement, etc.). BCA damage calculations should use the depreciated replacement cost of the structure/improvement, and the values used for the damage calculations should never include the value of the underlying land. Figure 37 shows the structure damages of a 2,000-square foot single-family home by flood depth for six different values per square foot, ranging from \$100 to \$350.

Figure 37: Structure Damages by Depth and Value per Square Foot



2,000-square-foot single-family home; USACE Generic depth-damage function

The Flood BCA Calculator attempts to minimize inconsistencies between analyses by including default values for both home sizes and values per square foot. These defaults are based on FEMA values but adjusted for inflation over time and can be used without external justification. The current version of the TWDB Flood BCA Calculator (v2.0, 2025) focuses on single-family homes, with apartments included as commercial properties. TWDB expects this to be sufficient for most BCAs, as single-family homes comprise approximately two-thirds of Texas's housing stock. However, future versions of the Calculator may include additional housing options such as duplexes, mobile homes, or condominiums.

8.3 Sample Project

A demonstration of how various inputs can change the BCA, a sample BCA using the TWDB Flood BCA Calculator v2.0 is presented here. This BCA uses real-world structure and 100-year RI WSE data for a real proposed project.

The sample project consists of several large detention areas with over 2,000 acre-feet of total capacity and associated drainage upgrades. Based on modeled Before- and After-Mitigation WSE, the project will reduce flooding to over 500 primarily residential structures and eliminate flooding in the 100-year event for approximately 160 structures. The project also includes ecosystem benefits related to the detention areas, which will be classified as urban green open space. This sample project does not include benefits related to street flooding, LWCs, recreational facilities, utilities, or agricultural lands. The project will remove approximately 2,400 feet of roadway from the floodplain, but sufficient information to estimate benefits related to this reduction in roadway flooding was not available.

First, the project benefits were calculated using the default values included in the TWDB Flood BCA Calculator. Then, various inputs were changed to observe how varying those inputs changed the total benefits calculation. The amended inputs included both subjective values about which different analysts could reasonably come to different decisions, such as value per square foot or length of analysis period, and objective values that are specific to individual projects, such as Median Household Income (MHI) in the study area and RIs of flooding; these are shown to demonstrate how they could impact the benefit calculus and why BCAs for similar projects in different locations may have significantly different results.

The first results shown use the default values included in the TWDB Flood BCA Calculator v 2.0 as of 2024, as presented in Figure 38. Based on these values, the benefits of the Project are \$18.4 million (Figure 38 and Figure 39).

Figure 38: TWDB Flood BCA Calculator v2.0 Default Values, 2024

Input	Default Value	User Value
Analysis period (years)	30	30
Year of analysis	2024	2024
Discount Rate	3.1%	3.1%
Federal mileage rate	\$0.68	\$0.68
Number of people per vehicle	1.67	1.67
Average vehicle value	\$29,052	\$29,052
Number of people per household	3	3
Number of workers per household	2	2
Number of employees per commercial structure	10	10
Autos per household	2	2
Property value per square foot	\$119	\$119
Small home (sq ft)	1,000	1,000
Average home (sq ft)	2,500	2,500
Large home (sq ft)	5,000	5,000
Contents value (as percent of residential home value)	100%	100%
Project Area Median Household Income*	\$72,284	\$72,284

Figure 39: Sample Project Total Impacts, Default Values

Project Impacts by Recurrence Interval	100 - year storm	
	Baseline	Project
Residential Flood Damage	\$155,952,650	\$108,607,740
Commercial Flood Damage	\$4,404,714	\$2,423,637
Flooded Streets	\$0	\$0
Utility Impacts	\$0	\$0
Agricultural Losses	\$0	\$0
Low Water Crossing Damages	\$0	\$0
Health and Safety Costs	\$41,822,729	\$32,084,324
Emergency Operations Costs	\$0	\$0

Flooded Structures by Recurrence Interval	100 - year storm	
	Baseline	Project
Flooded residential structures	537	380
Flooded Residents	1611	1140
Flooded commercial structures	28	23
Flooded Employees	280	230

Figure 40: Sample Project Results, Default Values

Analysis Period (years) **30**

Event Damages	Baseline	Project
100 - year storm	\$202,180,093	\$143,115,701
Annualized Damages	\$2,021,781	\$1,431,143

Damage Reduction Benefits	\$10,751,611
Recreation Benefits	\$0
Other Benefits	\$7,689,823
Total Benefits	\$18,441,434

Subjective values over which the analyst has some decision-making capacity that may have a large potential to impact the benefit calculation are the property value per square foot and the analysis period. Structure value is controlled by both the value per square foot and the structure size. Increasing the value per square foot from the 2024 default value of \$119 to \$250 increases the total benefits of the “Sample Project” from \$18.4 million to \$25.7 million (Figure 41), an increase of 40 percent.

Figure 41: Sample Project Results, Property Value Increase

Analysis Period (years) **30**

Event Damages	Baseline	Project
100 - year storm	\$333,679,452	\$234,738,776
Annualized Damages	\$3,336,761	\$2,347,364

Damage Reduction Benefits	\$18,010,374
Recreation Benefits	\$0
Other Benefits	\$7,689,823
Total Benefits	\$25,700,197

Further increasing the value per square foot to \$400 increases the benefits to \$34.0 million, an increase of 85 percent.

The example project consisted of structures in the Small, Average, and Large Home categories. Reverting to the 2024 default value per square foot and changing all structures to “Small” homes decrease the benefits to \$14.2 million. Changing all structures to “Average” results in benefits of \$17.4 million, and all “Large” homes result in benefits of \$23.6 million. The household size can also impact the benefit calculations, especially if the project will prevent displacement costs, which are calculated on both the per-household and the per-person bases. Reverting to the original structure size but increasing the average household size from 3 to 5 persons per household

increases the benefits to \$20.0 million. These are both differences that can occur between a larger geography, such as a county, and a more specific geography, such as the census tract or block group; this example emphasizes the importance of using information that matches the actual project area as closely as possible.

The analysis period can also have a significant impact on the benefit calculation. In this example, extending the analysis period from the default value of 30 years to 50 years increases the benefits from \$18.4 million to \$24.0 million (Figure 42).

Figure 42: Sample Project Results, 50-year Analysis Period

Analysis Period (years)	50	
Event Damages	Baseline	Project
100 - year storm	\$202,180,093	\$143,115,701
Annualized Damages	\$2,021,781	\$1,431,143

Damage Reduction Benefits	\$14,029,292
Recreation Benefits	\$0
Other Benefits	\$10,034,103
Total Benefits	\$24,063,395

The MHI value is used to calculate the marginal utility multiplier, as described in [Section 7.0](#). The default value is the Texas MHI of \$72,284. Keeping this default MHI value in the analysis results in a Marginal Utility value of 1.0, with no subsequent weighting for out-of-pocket costs. When using a localized MHI value of \$45,000, the Marginal Utility increases to 1.77, and total benefits increase from \$18.4 million to \$24.5 million (Figure 43 and Figure 44).

Figure 43: Sample Project Total Impacts, Marginal Utility Factor

Project Impacts by Recurrence Interval	100 - year storm	
	Baseline	Project
Residential Flood Damage	\$260,819,216	\$181,474,615
Commercial Flood Damage	\$7,778,774	\$4,280,170
Flooded Streets	\$0	\$0
Utility Impacts	\$0	\$0
Agricultural Losses	\$0	\$0
Low Water Crossing Damages	\$0	\$0
Health and Safety Costs	\$41,822,729	\$32,084,324
Emergency Operations Costs	\$0	\$0

Flooded Structures by Recurrence Interval	100 - year storm	
	Baseline	Project
Flooded residential structures	537	380
Flooded Residents	1611	1140
Flooded commercial structures	28	23
Flooded Employees	280	230

Figure 44: Sample Project Results, Marginal Utility Factor

Analysis Period (years)	30	
Event Damages	Baseline	Project
100 - year storm	\$310,420,719	\$217,839,109
Annualized Damages	\$3,104,176	\$2,178,369

Damage Reduction Benefits	\$16,852,821
Recreation Benefits	\$0
Other Benefits	\$7,689,823
Total Benefits	\$24,542,644

The study area for the MHI that is used for a BCA should match the actual project area (in location and size) as closely as possible. Smaller projects should use specific census tracts or block groups; larger projects may use larger geography. For example, Harris County has an overall MHI of \$70,789, which results in a Marginal Utility value of 1.03. However, specific census tracts within Harris County have MHI that ranges from \$36,000 to \$250,000, with accompanying Marginal Utility values of 2.31 and 0.23, respectively. (Note that marginal utility values below 1.0 are not applied to the BCA in either the TWDB Flood BCA Calculator or the FEMA BCA Toolkit.)

While each of these individual changes results in relatively modest increases in benefits, making several together (increasing the property value per square foot to \$250, decreasing the MHI to \$45,000, and extending the analysis period to 50 years) increases the benefits from \$18.4 million to \$48.7 million, more than doubling the benefits with an increase of 160 percent (Figure 45).

Figure 45: Sample Project Results, Multiple Variables

Analysis Period (years)

50

Event Damages	Baseline	Project
100 - year storm	\$542,650,036	\$379,646,470
Annualized Damages	\$5,426,446	\$3,796,427

Damage Reduction Benefits	\$38,717,475
Recreation Benefits	\$0
Other Benefits	\$10,034,103
Total Benefits	\$48,751,578

Changes from Default Values: \$250 Value per Square Foot; \$45,000 MHI; 50-year Analysis Period

In addition to changing the parameters in the Default Values tab of the model, it is also important to consider the sensitivity of the results to other inputs, some of which may be calculated outside of the BCA model. For example, if the WSE that are labeled as 100-year RI are more indicative of a 70-year RI due to increasing flood risks over time, the benefits increase from \$18.4 million to \$23.0 million. The same WSE for a 50-year RI results in benefits of \$29.2 million. However, this is a calculation that must be made during the H&H process of project analysis, not the BCA process.

Additionally, FFEs are usually estimated based on foundation heights. While the most accurate foundation height data comes from individual surveys, these are rarely cost-effective or timely to complete solely for BCA purposes. Potential sources for estimating FFE include Google Street View images, drone imagery, NSI 2.0, FEMA engineering guidelines, and data imputation techniques. This is also true for ground surface elevations, which often rely on LiDAR data in the absence of detailed survey data. Some detailed H&H data for drainage projects may have ground surface elevations at manhole covers but will have to be interpolated for points between certain locations. In the Sample Project, the neighborhood consists of mostly slab-on-grade houses, so foundation heights were assumed to be 6 inches. Decreasing the foundation heights to 4 inches increases benefits from \$18.4 million to \$20.0 million, while increasing foundation heights to 12 inches decreases benefits to \$17.3 million.

As shown, even small differences in assumptions when combined can result in large impacts on the benefits. Even without incorporating the marginal utility multiplier, the benefits calculated for the Sample Project can range from \$14 million to \$34 million by changing the structure size, foundation height, value per square foot, length of analysis period, and household size. These are important considerations when both conducting and reviewing analyses, and in most cases should be reached through reasonable consensus with multiple people familiar with the project and the study area. Sufficient documentation should always be provided so that anyone reviewing the project can follow how and why decisions were made about

each aspect of the analysis. Analysts may also present suggested alternative values for key parameters that could be used for such sensitivity testing or provide the results of a broader uncertainty analysis using such methods as Monte Carlo simulation where this has been conducted.

Table 28: Impact on Benefits of Changing Parameters

Parameter	Low Value	High Value	Benefits Range (\$M)
Structure Value per Square foot	\$119	\$400	\$18.4 - \$34.0
Home Size	Small	Large	\$14.2 - \$23.6
Average Household Size (Number of people)	3	5	\$18.4 - \$20.0
Analysis Period (Years)	30	50	\$18.4 - \$24.0
Median Household Income*	\$45,000	\$72,284	\$18.4 - \$24.5
Recurrence Interval (Year Storm)*	50	100	\$18.4 - \$29.2
Foundation Heights (Inches)*	4	12	\$17.3 - \$20.0

* In these cases, the lower value produces the higher benefit number.

9.0 Costs

Project costs consist of the economic resources (in the form of the inputs of capital, land, labor, and materials) needed to develop and maintain the new or improved infrastructure over its lifecycle. The total project costs for the BCA are comprised of two distinct costs: capital costs, sometimes called first costs, and ongoing operations and maintenance (O&M). These costs must be discounted using the same discount rate used for the benefits, be in the same dollar year, and should cover the same analysis period.

9.1 Capital Expenditures

Capital costs should include all costs necessary to make the project function and produce the benefits identified, including not only construction costs but also design, right-of-way, utility relocations, permitting, and other support costs that are necessary for project completion. The project cost estimate or budget should outline the costs for the development of the overall project and should itemize specific costs. General categories could include environmental, preliminary engineering and design, right-of-way, permitting, and administration, as well as the actual construction costs of materials, equipment, and labor.

9.2 Ongoing Operations and Maintenance

O&M costs cover a wide array of costs required on a continuing basis. The O&M costs of the project through the analysis period should be included in the BCA and should be directly related to the proposed service plans for the project. O&M costs should be projected for both the no-build baseline and the proposed project. For projects involving the construction of new infrastructure, total O&M costs will generally be positive, reflecting the ongoing expenditures needed to maintain the new asset over its lifecycle. For projects intended to replace, reconstruct, or rehabilitate existing infrastructure, however, the net change in O&M costs under the proposed project may be negative, as newer infrastructure may require less frequent and less costly maintenance to keep it in service than would an aging, deteriorating asset. The discounted O&M cost increase (or decrease) should be added (or subtracted) to the discounted capital costs to develop a total project cost for comparison to project benefits.

10.0 Recommendations for Further Research

TWDB has made every effort to present the best available data regarding the benefit categories presented here. However, there are several areas that have been identified for further research, primarily in the realm of life safety benefits. These include:

- » Factors that influence motorists' decision to detour around flooded streets
- » Factors that influence the likelihood of successfully fording flooded streets, including water depth, velocity, and vehicle characteristics
- » Incidence of injuries, infectious disease, and other health issues following flooding, by water depth and potential duration
- » Monetary impacts of injuries, infectious disease, and other health issues, including direct healthcare costs as well as indirect costs such as lost productivity
- » Utility, roadway, and other physical infrastructure damages by water depth and velocity
- » Agglomeration benefits

As new research on these topics becomes available, TWDB intends to update this Guidance Document and the associated **TWDB Flood BCA Calculator** tool.

Endnotes

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2. North Carolina Division of Emergency Management, FEMA Region IV, and NCAFP. "National Flood Insurance Program/Community Rating System." October 2011. <https://terms.ncem.gov/TRS/publicFileViewer.do?jsessionid=2aa47035549780080ef8a587dfe3?codId=A23F55AB7973524F>
3. The 1936 Flood Control Act states, "The Federal Government should improve, or participate in the improvement of, navigable waters or their tributaries, including watersheds thereof, for flood-control purposes, if the benefits to whomsoever they may accrue are in the excess of the estimated costs, and if the lives and social security of people are otherwise adversely affected."
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5. Dodds, Luke. Mitigation Saves? High Discount Rates Undermine FEMA's Efforts to Promote National Resilience. Homeland Security Affairs. Volume 18. May 2022.
6. As OMB Circular A-94 states, "Constant-dollar benefit-cost analyses of proposed investments should report discounted net benefits and other outcomes determined using the real discount rate [of 3.1%]. [This rate] is updated every three years and is available on the OMB home page." <https://www.wbdg.org/FFC/FED/OMB/OMB-Circular-A94.pdf>
7. Title 31 Part 10 Chapter 361 Subchapter C RULE §361.38. <https://www.sos.state.tx.us/texreg/>
8. For the purposes of FRM projects, pre-calculated benefits are available for acquisitions, elevations, mitigation reconstruction, and hospital generator projects. <https://www.fema.gov/grants/guidance-tools/benefit-cost-analysis/streamlined-bca#pre-calculated-benefits>
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12. FEMA. Freeboard. 8 July 2020. <https://www.fema.gov/glossary/freeboard>
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