

Appendix F
Benefit-Cost Analysis of
Flood Protection Measures

Acronyms used in Appendix F:

| | |
|-----------------|---------------------------------------|
| AA _B | Average Annual Benefits |
| AA _C | Average Annual Cost |
| AA _D | Average Annual Damages |
| BC | Benefit-to-Cost |
| BFE | Base Flood Elevation |
| EAD | Expected Annual Damages |
| FEMA | Federal Emergency Management Agency |
| NED | National Economic Development |
| O&M | Operation and Maintenance |
| PV | Present Value |
| RED | Regional Economic Development |
| USACE | United States Army Corps of Engineers |

Benefit-Cost Analysis of Flood Protection Measures

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1. Introduction

This memorandum presents the steps necessary to conduct a benefit-to-cost (BC) analysis of flood protection measures according to standard methodologies employed by the US Army Corps of Engineers (USACE) and the Federal Emergency Management Agency (FEMA). BC analyses for flood protection projects involve the determination of benefits as damages avoided over the life of the project and comparing them with the construction and operation and maintenance (O&M) costs associated with the project. Damages avoided include physical damages to buildings and infrastructure due to flooding and/or erosion, as well as nonphysical damages such as loss of income and transportation damages. Four damage categories will be considered in the detailed watershed plans (DWPs): property damage, erosion damage, transportation damage, and recreation damage.

2. Benefit-Cost Analysis

BC analysis is commonly applied to determine the adequacy of a project to meet its goals. This type of analysis helps define the best composition of a project, identify whether a project is worth the investment, and compare and choose among competing alternatives.

In the case of flood protection, BC analysis is intended to provide a measure of how a project will provide National Economic Development (NED) benefits, which are defined as “increases in the economic value of the goods and services that result directly from a project.”¹ If the NED benefits of implementing a project are greater than the implementation costs (NED costs), then the BC ratio (NED benefits divided by NED costs) will be greater than one and the project will make a positive impact on the economy.

If there are several competing projects all of them with a BC ratio greater than one, the project with the highest NED net benefits (NED benefits minus NED costs) is the one that should be implemented; however, that project may not be the one with the greatest BC ratio.

The concept of NED benefits can be extended to regional economies by designation of Regional Economic Development (RED) benefits, which are the damages avoided to the regional economy by deploying of a flood protection project.

The subsequent sections discuss all of the components that need to be addressed when conducting BC analyses.

¹U.S. Army Corps of Engineers. 1988. *National Economic Development Procedures Manual—Urban Flood Damage*. Water Resources Support Center. Institute for Water Resources. IWR Report 88-R-2. Ft. Belvoir, Virginia.

2.1 Definition of Benefits and Costs

As noted, benefits are defined as damages avoided; therefore, the benefits of a project are equal to the damages without the project minus the damages with the project. If the project is technically sound, the damages with the project should be less than the damages without it and the net benefits will be positive.

Most flood damage is physical and includes structural damage to buildings, loss of contents in those buildings, damage to infrastructure, and damage to special or unique facilities. Nonphysical damage includes income loss for wages and profits to businesses, emergency response, temporary relocation, and post-flood cleanup.

Flood protection projects can be one or a combination of flood barriers (levees and floodwalls), building elevation, building relocation, and floodproofing. The costs of the project are mainly the capital cost of construction and O&M costs consisting of periodic inspection, preventive maintenance, and repairs throughout the useful life of the project.

2.2 Discounting Procedures

Flood protection projects provide benefits throughout a defined useful life that depends on the type of project. A levee may have a useful life of 50 years, whereas relocation of a house outside the floodplain is a permanent solution. Every year that the project performs its functions provides benefits and, in principle, requires some expenditure, although most of the cost is incurred during construction. Therefore, the concept of present value (PV) is applied to compare these two series of unevenly distributed benefits and costs.

PV is a basic concept of engineering economics that accounts for the time value of money. To calculate the PV, the series of benefits accrued and the series of costs incurred every year are discounted using compound interest procedures. The discount rate used is typically set by the federal government and recently has varied between roughly 3 and 7 percent. Figure 1 illustrates the discounting process.

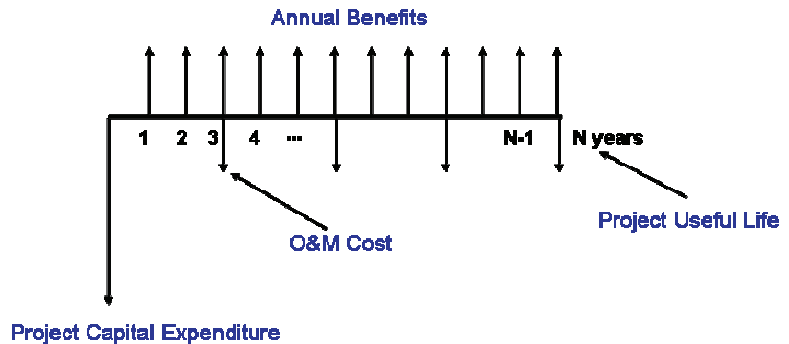


Figure 1. Discounting process to compare benefits and costs using present values.

Standard economic engineering textbooks provide formulas to convert a uniform series of “payments” to their present value. All these formulas are based on the fact that *PV* for an amount *P* accrued in year *t* is

$$PV = \frac{P}{(1+i)^t} \tag{1}$$

where *i* is the discount rate.

Conversely, the *PV* can be transformed into a series of equal amounts *A* over a given number of years *n* using the formula

$$A = PV \frac{i(1+i)^n}{(1+i)^n - 1} \quad (2)$$

2.3 BC Ratio Computation

Once the PVs of benefits and costs have been estimated, the BC ratio of the project can be computed using the formula

$$BC = \frac{PV_B}{PV_C} \quad (3)$$

where PV_B is the present value of the benefits and PV_C is the present value of the costs.

Equivalently, the BC ratio can be computed using the annual “payments” resulting from Eqn. 2. When applied to PV_B , the resulting uniform amount corresponds to the average annual benefits AA_B . Similarly, when Eqn. (2) is applied to PV_C , the uniform amount is the expected annual cost AA_C . Therefore, the BC can also be computed as

$$BC = \frac{AA_B}{AA_C}$$

The BC ratio can be used to evaluate whether a project is cost-effective. If the BC ratio is greater than unity, the project benefits exceed the costs and the project can be considered cost-effective. Vice versa, a project with a BC ratio less than one is not cost-effective and should not be considered.

Similarly, the net benefits of the project are equal to

$$NB = PV_B - PV_C$$

If the net benefits are positive, then the project is cost-effective and the BC ratio is greater than one. When several alternative project formulations are being considered, the project with the greatest net benefits (not the greatest BC ratio) is the optimal choice.

3. Estimation of Flood Damages

3.1 Physical Damages

As stated earlier, physical damages include structural damage to buildings (residential, commercial, industrial, public), loss of contents in those buildings (equipment, furnishings, raw materials, inventory), damages to infrastructure (roads, railways, sewers, power lines and other utilities), and damages to special facilities (power plants, hospitals, wastewater treatment plants). Physical damages may correspond to property damage, erosion damage, or transportation damage, although the majority of physical damages due to flooding are generally property damages. For all three damage categories, a floodplain inventory is necessary to understand what assets are at risk.

Physical damages depend on the severity of the flooding event. For riverine flooding, the severity is dictated mostly by the flooding levels but also by high flow velocities and duration of flooding. For coastal flooding, the inundation damage may be worsened by wave action. The severity of flooding is typically estimated using hydrologic and hydraulic

models to simulate the water surface elevations and flow velocities caused by storm events of various magnitudes.

3.1.1 Hydrologic and Hydraulic Modeling.

Hydrologic models are used to estimate the peak flows that are caused by a range of rainfall events. These models simulate physical watershed processes to convert rainfall into runoff. Modeling is typically performed for individual storm events of varying severity, for example the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year storms. The result of hydrologic modeling is typically the relationship between peak flows and their probability of occurrence shown in Figure 2. A relationship like this can be determined for any given location along a stream.

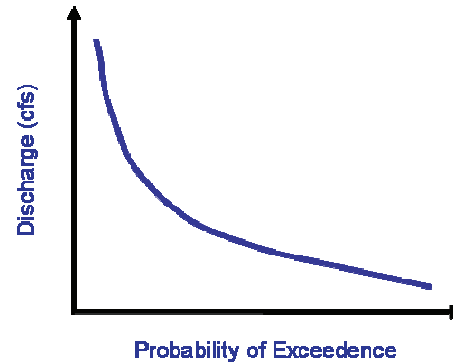


Figure 2. Flow frequency relationship for a given location.

Figure 2 shows that events that result in large peak flows have less probability of being exceeded. For example, the so-called “100-year flood” has a peak flow with a one-percent chance of being exceeded in any given year, whereas the “2-year flood” has a 50 percent exceedence probability.

A hydraulic model takes the peak flows resulting from the hydrologic model and estimates water surface elevations. One result of hydraulic modeling is the horizontal extent of the flooding caused by a given event. This area called the floodplain is determined by intersecting the flood elevations with the terrain. Floodplains for severe storms cover greater area than those for lesser events. The second result from hydraulic modeling is the relationship between flood elevations and probability of exceedence shown in Figure 3.

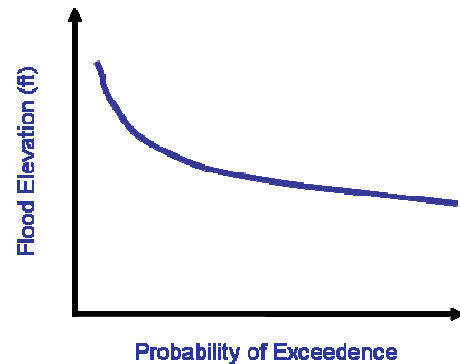


Figure 3. Flood depth- frequency relationship for a given location.

This relation follows the trend in Figure 2 in that severe events that produce high flood elevations have a low probability of exceedence. Curves like Figure 2 characterize the flood hazard at a given location. For FEMA regulatory purposes, the “100-year flood” elevations (also known as the Base Flood Elevations, BFEs) are used.

3.1.2 Floodplain Inventory. The damages caused by a flood reaching a given elevation are a function of the flooding depth inside buildings that causes damages. Therefore, the zero-damage elevation, typically the elevation of the lowest occupied floor in each building, is necessary to determine the depth of the flood waters inside. Similarly, for utilities, roads, bridges and other infrastructure, it is possible to determine a zero-damage elevation below which the asset is not expected to sustain damages.

A floodplain inventory is needed to determine these zero-damage elevations as well as the types of buildings and other assets at risk.

Residential. In residential properties, flooding damages the structure and its contents. It is also possible that high velocity flows can erode the stream banks a cause loss of property. The floodplain inventory for residential buildings must include a topographic survey of first floors as well as characterization of the type of residence: one story or multi-story, with or without basement, detached or attached, single family or multi-family.

The residence type is used to determine the replacement value of the structure (with or without depreciation), which is the basis to estimate structural and content damages. Standard building industry data can be used to determine the replacement value, for example R.S. Means or Marshall & Swift manuals.

Contents are typically estimated as a fraction of the replacement value, which insurance companies typically assumed to be 50 percent of the building replacement value.

Loss of property due to erosion can be estimated as the value of the structures deemed at imminent risk of failure to erosion.

Commercial / Industrial. Damages to non residential buildings also include structure and contents but the characterization is building specific due to the wide range of operations that can take place in various commercial and industrial outfits. Losses can also stem from damaged raw materials and products that may be warehoused.

Infrastructure. Physical damages to roads, bridges, power plants, sewers, water and wastewater treatment plants and similar infrastructure is difficult due to the unique nature of these systems. In most circumstances, damage evaluation requires detailed knowledge of each system and its operations and is best acquired using data from previous floods. In the absence of more detailed information, transportation damage (including both physical damage and emergency response costs) may be estimated as 15% of property damage (structure and contents).

3.1.3 Damage Curves. The discussion above indicates that physical damages depend on the depth and possibly the velocity of water and the duration of flooding affecting the buildings in the floodplain. These damages are typically estimated using depth-damage curves that relate the depth of water above the lowest occupied floor with the percent damage to a structure and its contents. For example, Figure 4 shows damage curves for structure and contents of a one-story single-family detached home. These curves are statistical averages from FEMA flood insurance actuarial data.

For non residential buildings these curves must be obtained on a site-specific basis for both the structure and the contents. Similar site-specific curves can be developed for other infrastructure, typically from data collected during a previous flooding event.

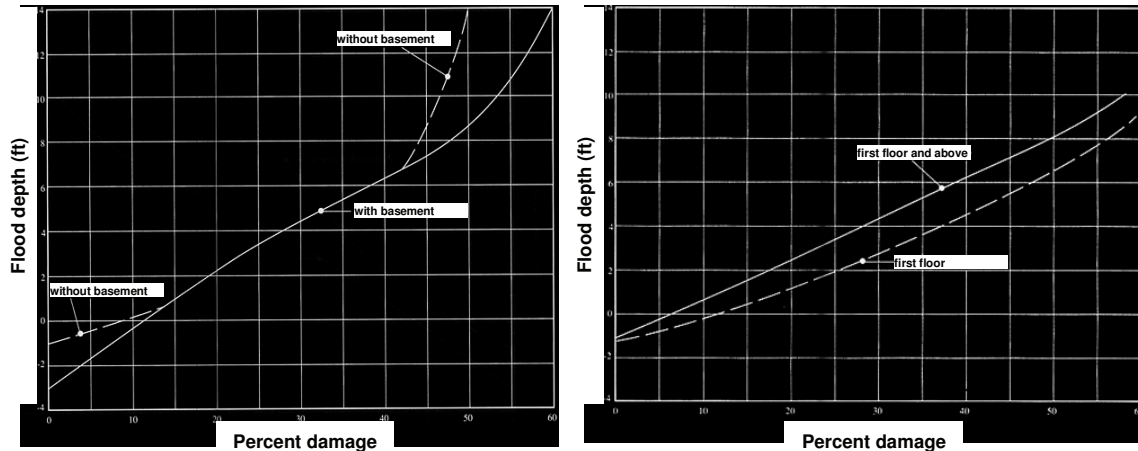


Figure 4. Damage curves for structure and contents in a one-story house².

3.1.4 Elevation-Damage Relationships. The building inventory, lowest-floor elevations, and depth-damage curves can be combined to produce an elevation-damage curve for the study area. This curve is the result of selecting an elevation and accumulating all of the damages for all assets that would occur if the flood waters reach that elevation. Figure 5 shows the typical shape of this curve.

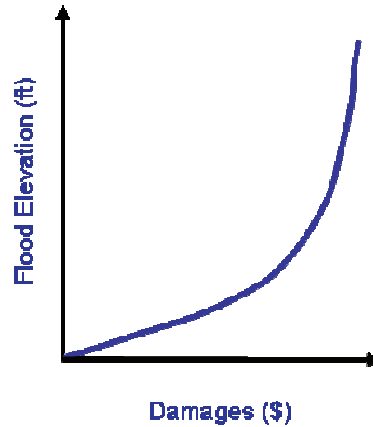


Figure 5. Elevation-damage relationship for a given study area.

3.1.5 Damage-Frequency Relationships. Because each flood elevation in Figure 5 is associated with the probability of the rainfall event that caused it, the elevation-damage curve can be transformed into a damage-frequency curve by assigning the exceedence probability to the corresponding damages as shown in Figure 6.

As expected, Figure 6 shows that there is a low probability for the greatest damages, which would be caused by severe but infrequent events. The curve levels off at these low probabilities indicating that the damages are virtually the same for very severe events that inundate all of the assets in the floodplain.

The area under the curve in Figure 6 is the expected annual damages (EAD), which is essentially the sum of all of the potential damages weighted by their probability of occurrence.

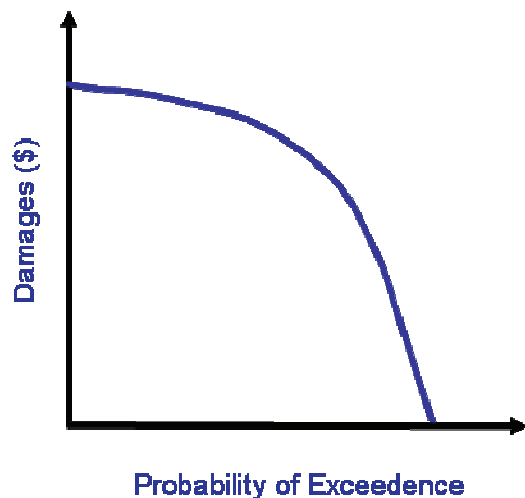


Figure 6. Damage-frequency relationship for a given study area.

²<http://www.usace.army.mil/inet/functions/cw/cecwp/NFPC/fphow/aces300.htm>

3.2 Nonphysical Damages

Nonphysical damages may include income loss for wages and profits to businesses, emergency response, temporary relocation, and post-flood cleanup. These damages are typically a lesser component of the entire flood damages but can be significant for commercial and industrial operations. Typically, nonphysical damages will correspond to the recreation and transportation damage categories.

The process to accumulate nonphysical damages is the same as for physical damages. The total dollar figure of damages is calculated for each flooding event and associated with the probability of the event to produce a curve similar to Figure 6. It is recognized that, in many cases, the necessary input data to perform a detailed analysis of non-physical damages for individual recurrence intervals may not be available. Nonphysical damages such as emergency response costs are included in the aforementioned estimate of transportation damage as 15% of property damage. When warranted, a detailed consideration of non-physical transportation damage might consider additional nonphysical damages such as income loss and relocation loss, although flood damage is not expected to be extensive enough to result in considerable damages in these categories.

Recreation damage may be developed in consultation with the USACE Economics Guidance Memorandum, which defines unit day values for recreation, benefits which may not be received due to access restrictions caused by flood conditions.

4. Damage Reduction by Flood Protection Measures

Flood protection projects can be one or a combination of installing levees or floodwalls, elevating structures, relocating out of the floodplain, residential buy-outs, and dry and wet floodproofing. Dry floodproofing involves deployment of flood shields along the perimeter of a building to keep floodwaters out up to certain level, typically not to exceed 2 or 3 feet. Wet floodproofing allows water to enter buildings but takes measures to minimize damage, such as utility relocation.

The effect of any flood protection measure is to reduce the damages. In terms of the depth-damage curves, flood protection measures have the effects shown in Figures 7 through 10.

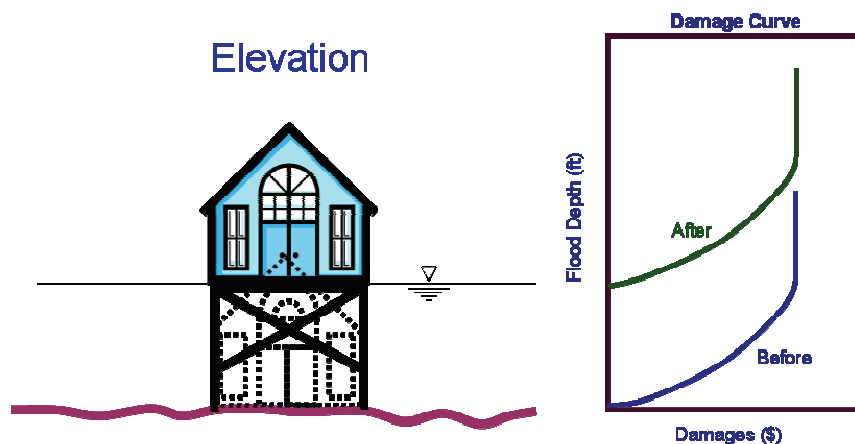


Figure 7. Damage reduction caused by elevating a structure. The damage curve shifts vertically.

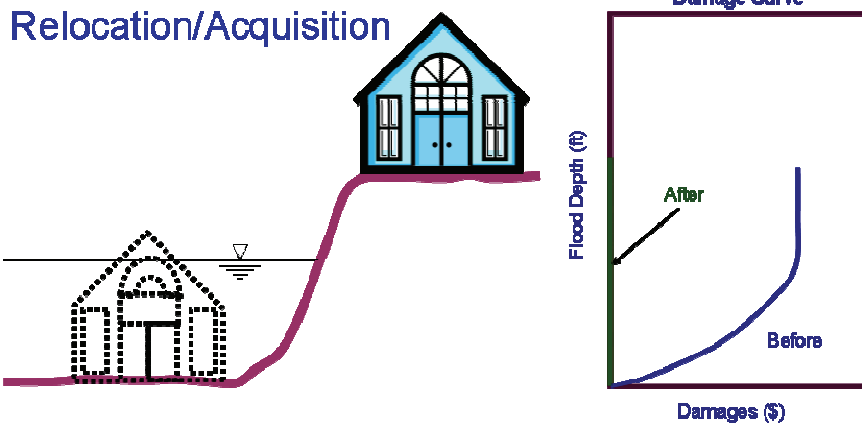


Figure 8. Damage reduction caused by removing a structure a structure out of the floodplain. The damages are zero.

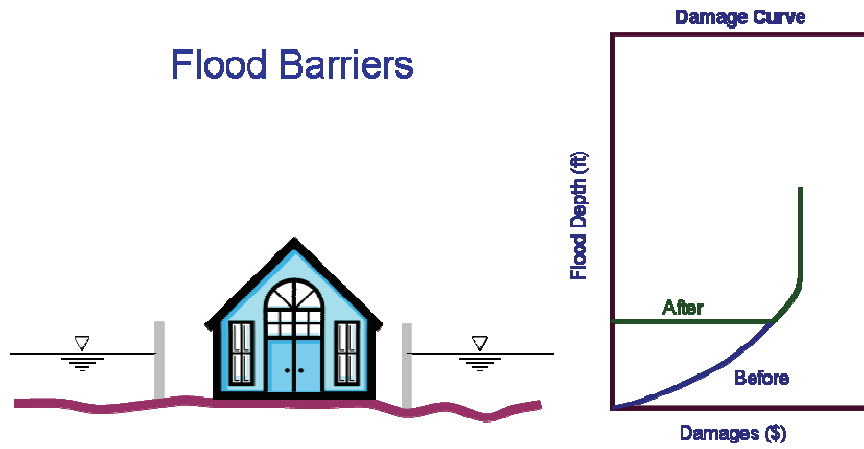


Figure 9. Damage reduction caused by building a levee or floodwall. Damages are zero up to the barrier top elevation and then become equal to the original curve when the barrier is overtopped.

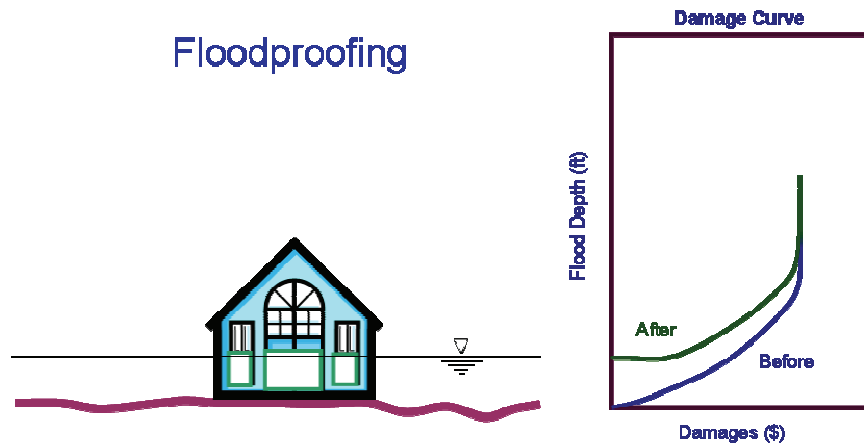


Figure 10. Damage reduction caused by floodproofing a structure. Damages are zero up to the height of the floodproofing measure and are reduced somewhat up to a certain elevation.

4.1 Damages Avoided

The process of computing damages avoided (benefits) requires estimation of the damage-frequency relationship after the flood protection project is implemented. This is basically the same sequence of computations explained above for the without-project condition. Figure 11 illustrates the result of the two parallel computations.

As noted, the area under each curve in Figure 11 corresponds to the average annual damages (AA_D). Therefore, the difference between the two areas is the expected annual damages avoided, which by definition corresponds the average annual benefits (AA_B). The benefits are accrued every year and correspond to the positive cash flow series in Figure 1. The series is assumed uniform throughout the life of the project but in reality, there will be changes in the building stock and economic activity in the floodprone area that may cause variations in the benefits.

4.2 Costs

The costs of the project involve all of the expenditures necessary for implementation. In the case of a levee, the cost includes study, design, and construction, plus O&M costs to maintain performance. For a residential buy-out, there is only the one-time cost of purchasing a number of houses in the floodplain, including demolition of the structures, restoration of the land, and closing costs. Floodproofing costs may be represented by one-time costs of utility relocation and periodic complete replacement of flood shields.

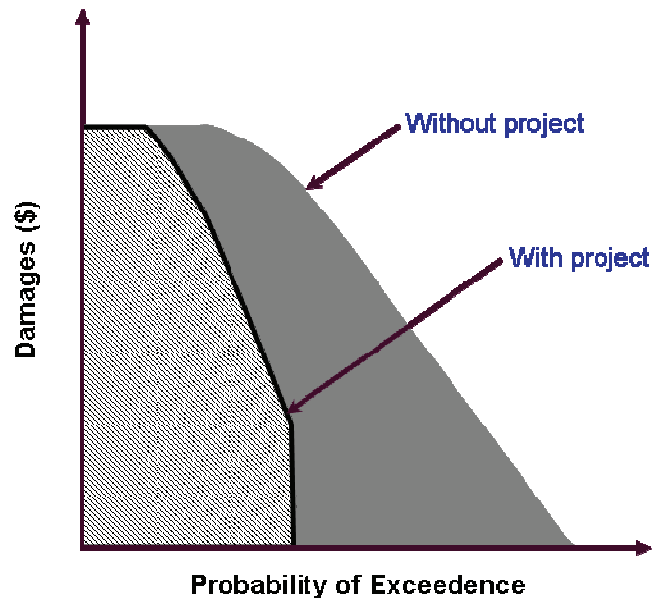


Figure 11. Damage frequency curves with and without project.

5. Summary

The BC analysis process for flood control projects consists of the following steps:

1. Delineate the study area
2. Inventory the study area to categorize buildings and infrastructure and estimate zero-damage elevations for each asset.
3. Select depth-damage relationships for all assets, including physical and nonphysical damages.
4. Perform hydrologic and hydraulic modeling for a series of events of varying severity to determine flood elevation vs. frequency relationships, with and without the project.

5. Calculate elevation-damage relationships accumulated for all assets in the study area, with and without project
6. Calculate damage-frequency relationships with and without project
7. Calculate average annual damages (AA_D), with and without project, as the areas under the corresponding damage-frequency curves.
8. Calculate the average annual benefits (AA_B) as the AA_D without project minus the AA_D with project.
9. Estimate the capital and O&M costs associated with the project.
10. Define the useful life of the project
11. Calculate the present value (PV) of the uniform annual series of AA_B and the PV of the cost including O&M. Alternatively, calculate the expected annual cost AA_C using Eqn. 2.
12. Compute the BC ratio as the PV of benefits divided by PV of costs, or as AA_B divided by AA_C . Compute the net benefits as the PV of the benefits minus the PV of the costs.