NATIONAL ECONOMIC DEVELOPMENT

US Army Corps of Engineers®

IWR INSTITUTE FOR WATER RESOURCES

FLOOD RISK MANAGEMENT

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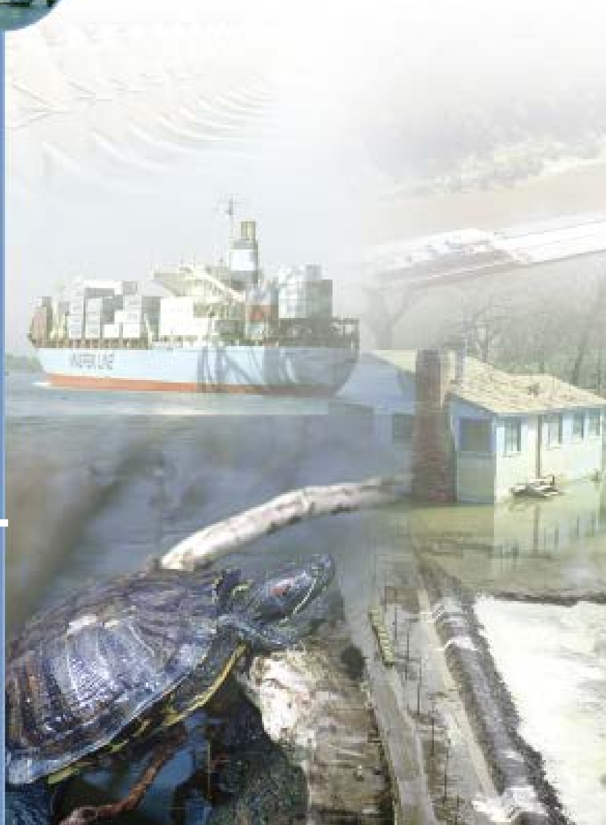

U.S. Army Engineer Institute for Water Resources

Other NED Manuals

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86-R-4	*Recreation, Vol. I: Recreation Use and Benefit Estimation Techniques*, March 1986.

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Foreword

The Corps of Engineers Planning Excellence Program is designed to build planning capability now and for the future. Economics is a vital component of the planning process and updating the National Economic Development manual series is a key element of the Planning Excellence Program.

I appreciate the efforts of the interdisciplinary team across the Corps, local sponsors and others who contributed to this manual. I am pleased to endorse its use as a tool for the Planning Community of Practice to reach out to all who are interested in our work.

Harry E. Kitch,

Planning Community of Practice Deputy,

Planning Civil Works

Transparent and defensible economic analysis provides a critical piece of information for decision making. It is incumbent on the economist to inform others about sources and validity of all the data, models, and assumptions that are part of the analysis. The economist must also acknowledge the key uncertainties, their impacts on the economic analysis, and the overall confidence in the economic values presented to decision makers.

Dr. David Moser

Chief Economist

U. S. Army Corps of Engineers

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1.1 Flood Problems

Introduction

Flooding is a natural and common global phenomenon. It is most often caused by an increase in stream flow beyond the point where the normal stream channel can contain the water. Water spills over the riverbanks and spreads out along the adjoining floodplain. Floodwaters may occupy the floodplain for a matter of hours, as in the case of flash floods, or for months, as occurred in some communities during the 1993 flood of the Mississippi River (story and photographs). Flooding is part of the hydrologic cycle in which water is continually recycled between the earth and the atmosphere. A flood "problem" requires two elements: flooding and development in the floodplain. This chapter provides a simple introduction to the flood problems of the United States.

Floodplains

The ***floodplain*** is a relatively level expanse of land carved out by the river. It is a natural extension of the river channel. In spite of the risks associated with flooding, people have long been drawn to occupying the floodplain because of the many benefits the floodplain provides: drinking water, food, transportation, hydropower, fertile land, ecosystem services, beautiful scenery, and more. Floodplain development in the U.S. includes every kind of land use imaginable. Historically, floodplain occupants rarely made accommodations for the river's eventual return to the land. Consequently, the stories of floods are often told in terms of how they affect the lives of the people in the floodplain. This is the social context of floods. Almost every culture on earth has an ancient flood story (click here to view more information about ancient flood stories). Although flooding is a natural part of the hydrologic cycle, it is the social context of floods that is of greatest concern in this manual.

As floodplain development increases, so does the damage caused by flooding. Communities try to protect themselves from floods with measures such as levees, dams, channel improvements and diversions. These structures have had some success, but they have also had the unintended consequence of creating a false sense of security.

Over 20,000 communities in the U.S. are subject to a substantial risk of flooding. Most of them participate in the National Flood Insurance Program (NFIP). With very few exceptions, most communities in the U.S. experience some kind of flooding, when the right set of circumstances occur (for example, after spring rains, heavy thunderstorms, winter snow thaws, the subsidence of land along a body of water, or heavy storms over a large body of water). Fires are the only disasters more common and widespread than floods. For some basic water facts see Where is Earth's Water.

Floods are neither mysterious nor freak occurrences. They are entirely natural events, most frequently caused by heavy rain. Floods rarely strike without some advance warning, and they usually occur in floodplains, where flooding can be expected. Floods are most destructive in that part of the floodplain known as the floodway, where the water flows fastest.

The structural approach to flood protection has often appeared to have solved a community's flood problem, but structures are neither permanent nor infallible. Levees, for example, can be eroded over time or become saturated and fail during extended periods of high flow. More importantly, no matter what level of flooding structures are designed for, there could come a time when the flood level exceeds the design flood.

Once the structural system of protection fails, for whatever reason, the flood damages could be greater than if the structures had never been put in place. This is a story repeated in the 20,000 plus flood prone communities of the U.S where additional development has occurred in the floodplain after the structural protection was provided (see National Wildlife Federation's "Coast and Floodplain Protection"). Figure 1 on the following page provides a basic illustration of a floodplain.

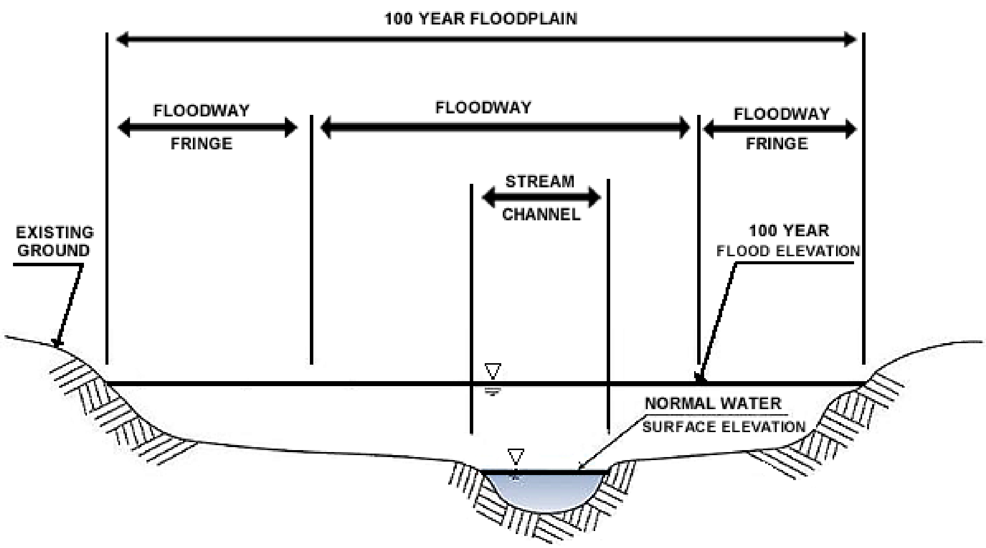


Figure 1: 100-Year Floodplain

View another typical floodplain map and cross section at Key Elements of a Floodplain.

Floods Are Natural

Floods are often associated with property damage and loss of life, but floods are a natural phenomenon and have an ecological context as well as a social one. They are necessary for the survival and health of ecosystems. The ecologies of floodplains, rivers and lakes have adapted to their annual and longer term water cycles. Wetlands and areas covered by shallow surface water especially rely on variations in water levels caused by natural fluctuations in flows to maintain their ecological balance and productivity. Many lands rely on sediments deposited during flooding to remain above sea level. Long-term changes to the water levels, through the use of reservoirs, channelization or levees, for example, can cause a change in the long-term succession of existing vegetation and habitat.

Population growth and economic activity have created incentives for altering the flow regime of surface water systems and the landscape of the floodplains. More predictable water flows were a goal of many watershed management programs during the 20th century. "Flood control," a term no longer in vogue, described the attitude of earlier generations that sought to control this natural occurrence through the construction of dams, levees, walls, diversion channels, channel dredging and realignment, and the drainage of wetlands. These efforts to control floods, although perhaps beneficial to economic activity, have often resulted in the decline of fish and wildlife habitats and the disruption of entire ecosystems. Wetlands have been eliminated, shoreline erosion has increased and the sediment filtration capabilities of the floodplains are among the ecosystem resources that have been lost or altered. An enlightened approach to inundation damage reduction takes these ecosystem values into consideration when planning and designing solutions to problems.

Floodplain Management

Floodplain management refers to the collaboration and planning executed to reduce flood damage and promote the preservation of floodplains. There are many impressive local initiatives to address floodplain management problems around the nation. Some of these involve partnerships with the Corps, others do not. For a sample of what local governments are doing to address these issues and to involve their citizens you may want to look at a few of these web sites:

- Association of State Floodplain Managers
- Floodplain Management Association
- Floodplain Management Plan, Clearwater, FL
- California Department of Water Resources, Los Angeles County
- National Association of Flood and Stormwater Management Agencies
- National Watershed Coalition

1.2 Causes of Flooding

The most common cause of flooding is when the volume of water exceeds the capacity of the river or stream channel. Rivers are natural drainage channels for surface waters. Surface waters are comprised of two components: *runoff* and *base flow*. Runoff is the precipitation that flows toward the rivers or streams on the surface or within the soil (subsurface runoff or interflow). Base flow is the part of stream flow that enters the stream channel from groundwater.

Stream flow is affected by a number of factors[1]. The most important of these for the purposes of this manual are:

(1) the amount and type of precipitation,

[1]The Corps Hydrologic Engineering Center (HEC) offers Hydrologic Engineering for Planning a hydrology course for non-hydrologists for those interested in more details than are provided here.

(2) the nature and condition of the drainage basin and
(3) climate.

During a rainstorm, the amount, intensity and duration of the rain, as well as the area of the storm and its path, determine the surface water runoff that reaches a stream.

The amount, intensity and duration of rain affect the ability of the land to absorb the precipitation, which further affects the rate of runoff. The area and path of the storm in relation to the size of the watershed determine the area contributing runoff. The runoff rate and the area affected together determine the volume of water that will pass a given point downstream. The volume of water moving through the channel and the channel's dimensions and conditions determine the nature and extent of the flood.

The shape, size, soil type and topography of the drainage basin are other factors that can affect the quantity of water reaching the stream and the timing with which it arrives. Although some of these factors are constant, some (such as the absorptive or shedding properties of the soil) vary with vegetation cover, season and previous rainfall.

Climate is an important issue to consider when studying floods because it can influence the relationship between precipitation and runoff. In colder climates, for example, frost makes most soil impenetrable if the soil contains moisture and therefore increases runoff. A large part of the year's precipitation may be stored in the form of snow in the northern part of the U.S. during winter. Heavy ice formation on rivers can also influence flooding. In hotter climates, parched soil can also influence runoff rates. In this way, the consequences and likelihood of floods are functions of the climate.

Floods may result from one or more of the following causes:

- Rainfall
- Snowmelt runoff
- Urban stormwater runoff
- Coastal storms, tsunamis, cyclones, hurricanes
- Ice jams and other obstructions
- Dam failure or the failure of some other hydraulic structure
- Catastrophic outbursts

Rainfall Flooding

As previously noted, rainfall is the most common cause of flooding in the U.S. In this case, the volume of water in the stream or river's channel simply exceeds its capacity to convey the water. As a result water spills out of the channel onto the adjoining lands of the natural floodplain, which may have been significantly altered by human activity.

Floods can rise slowly or quickly. In many areas they may develop over a period of days. Flash floods can be extremely dangerous because they are unanticipated. They usually happen on small watersheds as a result of a torrential downpour, often caused by heavy thunderstorm activity. In a flash flood, stream flow peaks within hours of the rainfall.

Snowmelt Flooding

During winter in some parts of the U.S., most of the precipitation may be stored as snow or ice on the ground. As temperatures rise huge quantities of water are released. Heavy runoff can result from the rapid melting of the snow under the combined effect of sunlight, winds and warmer temperatures. If the ground is frozen, the water produced by the melting snow is unable to penetrate and runs off into streams and lakes. Flooding becomes even more severe if the snowmelt runoff is compounded by runoff from concurrent heavy rainfall. For this reason, the risk of a compound flood problem is increased the later the spring thaw occurs. Snowmelt explains the prevalence of heavy spring runoff and flooding in some parts of the country.

Urban Drainage (Stormwater Runoff) Flooding

Urbanization drastically alters the drainage characteristics of the land. The slanted roofs, downspouts, storm gutters and stormwater conveyance systems increase the volume and rate of surface runoff. The urban runoff from intense rainfall can exceed the carrying capacity of the sewer system, creating a backup in the system. This backup often causes flooding of basements and low lying roads. Urban stormwater runoff can also cause local rivers and the urban area itself to flood. Although the impact on a major river may be minimal, the carrying capacity of small streams can be quickly exceeded, causing localized flooding and erosion problems.

Coastal, Tsunami and Hurricane Flooding[2]

Coastal flooding can occur on the Great Lakes, islands, or communities near or connected to the seas. Wave run-up, erosion, wind, estuarine flows, inland flooding, coastal storms, storm surge, tides, and other forces can lead to coastal flooding.

Tsunami is a Japanese term for “harbor wave.” A tsunami, also known as a tidal wave, is the most spectacular coastal flooding event. A tsunami actually has nothing to do with the tides. An undersea movement such as an earthquake or a landslide causes a disturbance that gives a

[2] For more information on this topics, please see the Coastal Storm Risk Management NED Manual.

vertical motion to the water column resulting in a tsunami. The mass of water that hits the shore can have both tremendous velocity as well as force behind it.

Estimating damages from these kinds of floods is very difficult because tsunamis are unique with respect to location, amplitude of waves and time between troughs. Because the source of the wave is always unknown, modeling these events remains a crude approximation. For an overview of recent tsunami events see NOAA's documentation of recent and historical tsunami events.

The following information about hurricane flooding is adapted from the FEMA Hurricanes site.

A hurricane is a tropical storm with winds that have reached a constant speed of 74 mph or more. Hurricane winds blow in a large spiral around a relative calm center known as the "eye." The eye is generally 20 to 30 miles wide, and the storm may extend outward 400 miles. As a hurricane nears land, it can bring torrential rains and high winds. Even more dangerous than the high winds of a hurricane is the storm surge, a dome of ocean water that can be 20 feet at its peak and 50 to 100 miles wide. Nine out of ten hurricane fatalities are attributable to the storm surge. A single hurricane can last for more than two weeks over open waters and can run a path across the entire length of the eastern seaboard. August and September are peak months during the hurricane season, which lasts from June 1 through November 30. Hurricanes are called "typhoons" in the western Pacific Ocean, while similar storms in the Indian Ocean are called "cyclones."

2005 Hurricanes

Storm damage and flood from hurricanes Katrina and Rita during the 2005 hurricane season produced extensive information documented through data, text, and photographs. Some useful files and links include:

- Hurricane Katrina: Analysis of the Impact of the Insurance Industry
- Hurricane Katrina: Harvard Medical School
- Katrina Index: Tracking the Variable of Post-Katrina Reconstruction
- NOVA: Storm that Drowned a City
- PBS: The Storm
- Corps of Engineers, New Orleans District: Hurricane and Storm Damage Risk Reduction System

Figure 2: 2005 Hurricanes

Heavy rains and ocean waters brought ashore by strong winds can cause flooding. The runoff systems in many cities are unable to handle such an increase in water because of the gentle topography in many of the coastal areas where hurricanes occur. Hurricanes are capable of producing copious amounts of flash-flooding rainfall. During landfall, a hurricane rainfall of 10 to 15 inches or more is common. If the storm is large and moving slowly, less than 10 mph, the rainfall amounts from a well-organized storm may be even greater. To get a generic estimate of the rainfall amount (in inches) that can be expected, divide the storm's forward motion by 100, i.e., Forward Speed/100 = estimated inches of rain.

Ice Jam Flooding

Ice jams are a major concern in some cold region parts of the country. Jams form during both the freeze-up and breakup periods of ice formation. They result from the accumulation of ice fragments that build up in a logjam fashion to restrict the flow of water. The jams act as a temporary obstruction to stream flow.[3]

During freeze-up, ice jams usually form where floating ice slush or blocks encounter a stable ice cover. The beginning of the ice jam is the toe and the upstream end is the head. The stable ice is usually frozen to the banks or is restricted from moving by the channel configuration. Generally, incoming ice fragments either submerge and deposit under the stable ice cover, pile up behind it, or both. Bridge piers, islands, bends, shallows, slope reductions and constrictions can increase the likelihood of a jam forming. Ice jams in the spring result from accumulated ice from the breakup of the upstream ice cover.

Two features of ice jams increase the risk of floods: (1) ice jams can be very thick, many feet thick in some cases, and (2) the underside of the ice cover is usually very rough. In an open stream the streambed is the only source of friction retarding the flow of water. The rougher the streambed, the greater the depth required to pass a given stream discharge. With an ice jam in place, frictional resistance is greatly increased and the flow depth has to be much greater than for open water. Add the depth of water needed to float the ice jam to the depth required to maintain the discharge and extremely high water

[3] The mechanics of ice jam flooding can be quite complex, for more information see the Ice Jam and Ice Flooding Clearinghouse.

levels can occur, even at relatively small discharges.

When an ice jam suddenly is released it produces a surge of flow that can move at very rapid speeds. This surge can carry and deposit chunks of ice that are as large as automobiles, presenting a significant increase in damage potential for these kinds of floods.

Dam Failure Flooding

Flooding can be caused from the failure of dams or other hydraulic structures. These failures can result in a wall of water being released in a surge down the river channel. The suddenness and magnitude of such an event can have obviously disastrous results.

Catastrophic Outburst Flooding

Outburst floods are more common in western Canada and other parts of the world than they are in the U.S. An outburst flood occurs when lakes dammed by glaciers or moraines suddenly drain and tons of water, mud and debris are released. The resulting floodwaters can pick up large quantities of sediments and transform into destructive debris flows. The random and often unpredictable nature of these kinds of events makes the estimation of damages resulting from them as difficult as estimating damages from dam failures. These types of floods are very infrequent; however, their especially disastrous results make them very important to consider and work to prevent.

Glossary of Terms

For a glossary of flood-related terms used by the U.S. Army Corps of Engineers see Glossary. A Water Words Glossary is available from the North American Lake Management Society. A Water Words Dictionary has been prepared by the Nevada Division of Water Resources

1.3 National Flood Damages

Floods are the most common natural disaster in the U.S. According to the Federal Emergency Management Agency (FEMA), part of the U.S. Department of Homeland Security, 10 million households in this country are located in areas of significant flood risk. Even so, 20 to 25 percent of all flood insurance claims are paid to people who live in low to moderate flood risk areas. Two of the most well-known flood events in U.S. history include the Great Midwest Flood of 1993 (which inundated large parts of nine states for up to four months, destroyed or heavily damaged 49,000 homes, caused at least $16 billion in property damage, and took 50 lives), and Hurricane Katrina in 2005 (which caused $75 billion in estimated physical damages and a death toll of 1,836).

Nationally, from 1929 through 2003, annual flood damages (measured in 1995 dollars) have ranged from a low of $18 million in 1931 to over $17 billion in 1993. National flood damages have averaged $2.4 billion annually. In half of those years, damages have been $1.3 billion or less. Total damages have exceeded $171 billion (data are not available for 1980-1982). To examine the data set from which these figures were taken, simply access the attached data file National Flood Damages or visit it at its original source at Flood Damage Data.

To understand the damages in a more personal context, consider Figure 3 below. If we think of flood damages as a head tax imposed by nature on the United States, that tax has varied from a low of $0.15 (1995 dollars) per year to a high of $66.16 per year and has averaged $11.42 per year for every man, woman and child in the U.S. from 1926 to 2003. If these average "taxes" were funds available for flood damage reductions, it would amount to about $3.6 billion a year in 1995 dollars based on a current U.S. Population of about 314 million.

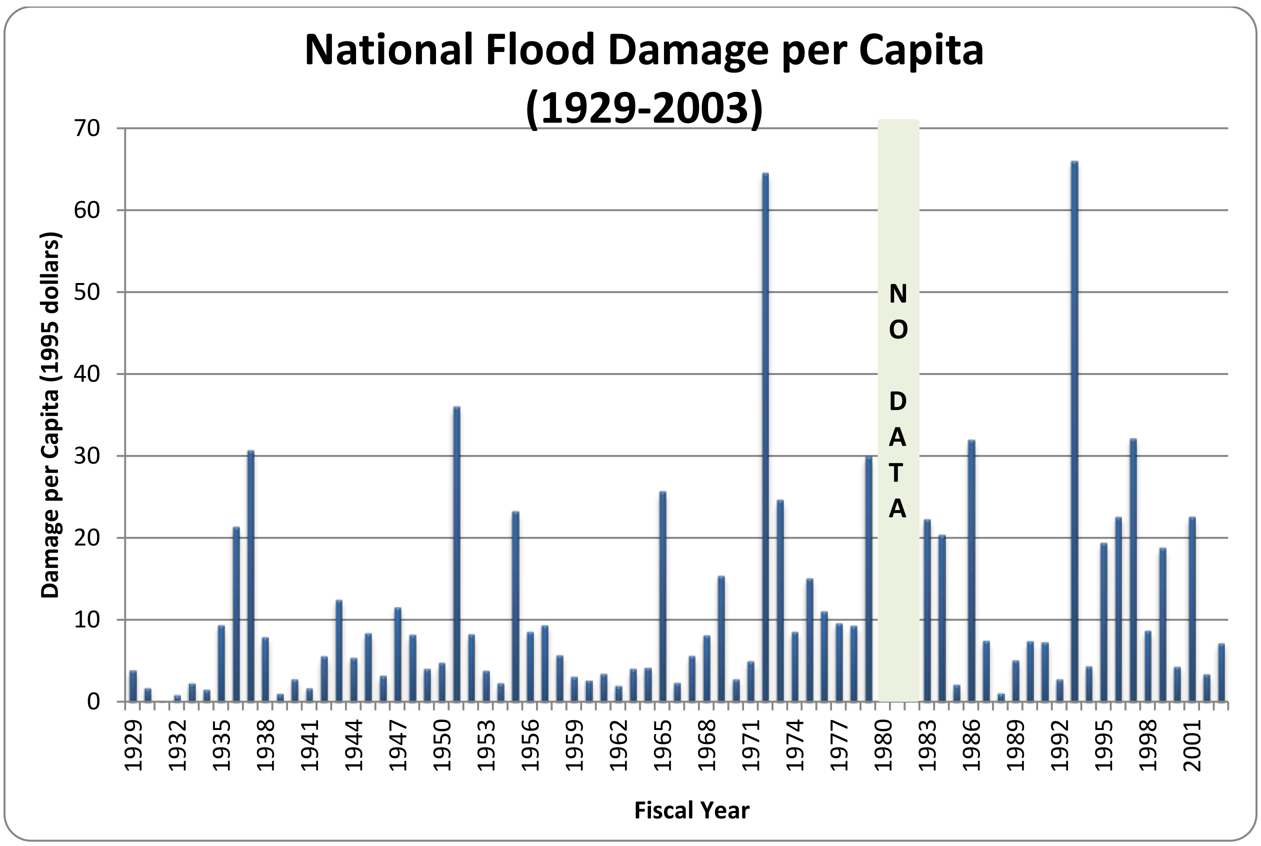


Figure 3: National Flood Damage per Capita

For a comprehensive discussion and history of flood damage data in the United States see Flood Damage in the United States 1926-2003.

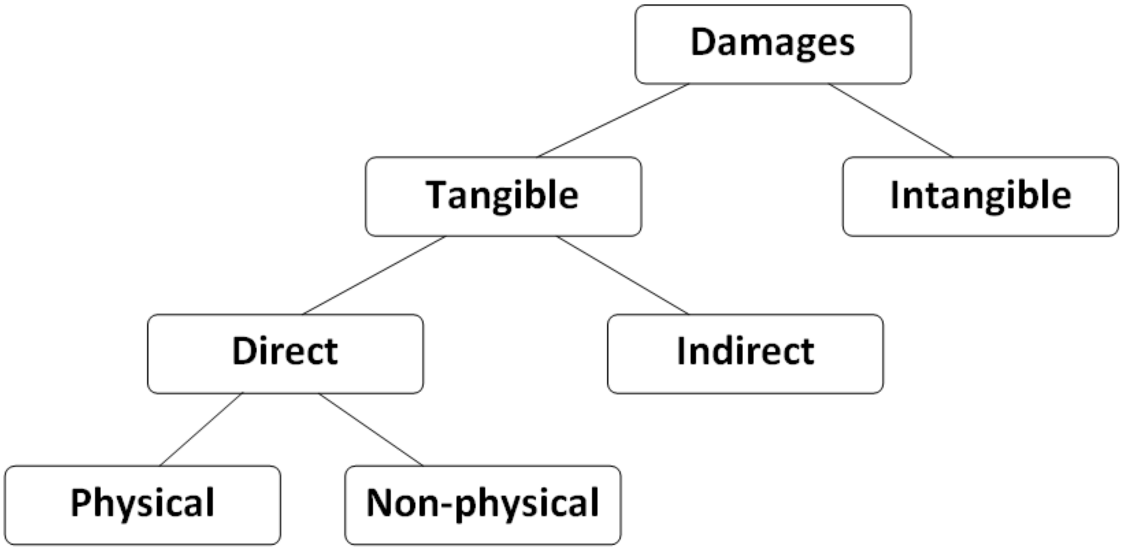
Flood Control Act of 1936

The damage data above clearly establishes the severe magnitude of the Nation's flood problems. In 1936, as a result of several devastating floods in the Midwest and the Northeast United States a National flood control policy was enacted by the Flood Control Act of 1936. This law created the program the USACE executes to this day. It is the seminal legislation for the urban flood damage reduction initiatives this manual addresses. The first four sections of the Act, which established flood control as a National policy, can be seen at Flood Control Act of 1936. The last sentence of Section 1 is particularly important because it establishes the use of benefit-cost analysis for the evaluation of flood control projects, a criterion later extended to other water resource projects as well.

The 1936 Flood Control Act has been revised and expanded many times since its passage. The estimation of flood control benefits, a term more recently replaced by inundation damage reduction benefits, began with the passage of this law. This manual summarizes the Corps' current best practice approaches to flood damage estimation.

1.4 Flood Damages

The 1936 Flood Control Act established the requirement for a benefit-cost analysis of flood control projects that continues to this day. Flood damage reduction is usually the major category of benefits for a flood risk management project. Flood damages can be classified in a variety of ways. See the diagram in Figure 4 below for the definitions and relationships between the different classifications of flood damages.



Tangible: Damages that are directly quantifiable (can typically be measured as monetary losses).
Intangible: Damages that cannot be readily or reliably quantified. Examples include injury, emotional response, or quality of life.
Direct: Damages that result from the actions of floodwaters. Examples include damaged automobiles, furniture, houses, or machinery.
Indirect: Damages that arise from the disruptions caused by flooding. Examples include lost investment and lost wages as a result of damaged goods.
Physical: Damages that occur to residential, commercial, industrial, institutional, and public property. Examples include damaged houses, warehouses, playgrounds, etc.
Non-physical: Direct damages that cannot be touched. Examples include income losses and emergency costs.

Figure 4: Classifications of Flood Data

Intangible Damages

Intangible flood damages are those that cannot be readily or reliably quantified (e.g., injury, emotional response, quality of life). Tangible flood damages are those that can be quantified in monetary or other discrete terms (e.g., acres, lives, structures, linear feet).

Flooding imposes many intangible costs to a community. Some of the more common examples include the following:

- Injury
- Peace of mind or trauma
- Inconvenience

- Isolation
- Evacuation from home
- Stress and anxiety
- Disruption of life
- Health issues

These intangible damages are not easily quantifiable and have not been included in the monetary assessment of flood damages. Although they are not easily quantifiable, it is still important to take intangible damages into consideration when managing flood risk.

Tangible Damages

Tangible damages are usually quantified and measured as monetary losses. Some tangible flood damages may be quantified in other terms. For example, we may speak of potential lives lost during a flood, or people at risk who live in a particular floodplain. Damages may be measured in acres, linear feet or other nonmonetary metrics.

Tangible flood damages may be direct or indirect. Direct damages result from the actions of floodwaters on property and structures. Indirect damages arise from the disruptions to physical and economic activities caused by flooding. For example, if a plant that produces canned tomato products is flooded it suffers direct flood damages to its cannery. If, as a result of the flood, local tomato growers not affected by the flood waters lose a buyer for their product they suffer indirect flood damages. Likewise, the can manufacturer located out of the floodplain that produces cans for the tomato plant also suffers indirect flood damages. Indirect damages are a negative spillover effect (externality) of flooding.

Direct Flood Damages

Physical:

- Destruction of degradation of property and contents as a result of contact with flood water
- Destruction of public infrastructure
- Permanent restricted use of land to reduce exposure to flood risk

Non-physical:

- Costs of rescue, flood fighting and cleanup
- Lost economic profit and wages resulting from flooded businesses
- Increased travel time and expenses to bypass flooded roads and bridges
- Short-term increases in prices and wages to business and individuals involved in a reconstruction effort

Figure 5: Direct Flood Damages

Tangible damages may be categorized in more ways than simply direct and indirect damages. It is common to collect flood damage information using one type of categorization and then to report it using another. For example, analysts may identify and collect content damage, structure damage, flood fighting costs, surplus losses and recovery costs information then aggregate it and report it as the broad land use damage categories of residential, commercial, industrial, public and other damages.

Types of tangible, direct flood damage

Flood damages are classified into two categories: physical damages and nonphysical damages. Each activity affected by a flood can experience loss in one or both of these classes.

i. **Physical damages**. Physical damages occur to residential, commercial, industrial, institutional and public property such as buildings, contents, automobiles, outside property and landscaping. Physical damages include the costs to repair roads, bridges, sewers, power lines and other infrastructure components. This type of damage also includes the direct costs and the value of uncompensated hours for cleanup after the flood.

ii. **Nonphysical flood losses**. Nonphysical flood losses include income losses and emergency costs. Income losses are the loss of wages and net economics profits to business over and above physical flood damages that usually result from a disruption of normal activities. Estimates of these losses must be derived from specific independent economic data for the interests and properties affected. Prevention of income losses result in a contribution to NED only to the extent that the losses cannot be compensated for by postponement of an activity or transfer of the activity to other establishments. Emergency costs include those expenses resulting from a flood that would not otherwise have been incurred. For example, the costs of evacuation and reoccupation, flood fighting and administrative costs of disaster relief; increased costs of normal operations during the flood; and increased costs of police, fire or military patrol. Emergency costs should be determined by specific surveyor research and should not be estimated by applying arbitrary percentages to the physical damage estimates.

Property Damage Categories

Property is often categorized as real or personal property. Real property is land and appurtenances, i.e., anything of a permanent nature such as structures, trees, minerals, including the interest, benefits, and inherent rights to use these things. Personal property, on the other hand, is any property that is not real property. Personal property can be tangible (e.g., furniture, equipment, automobiles and clothing) or intangible (e.g., business interest, stocks and bonds). Flood damage can accrue many kinds of real and personal property. The most common categories of flood damages to property include:

- Structure damage
- Content damage
- Infrastructure damage
- Damage mitigation or flood fighting costs
- Costs associated with evacuation
- Net income losses (referring to net losses in net economic profit)*
- Traffic disruption
- Clean-up and recovery costs

*Note that postponed and transferred profits are not included in “losses.”

Clean Up and Debris Removal

Structure Damage

Content Damage

Flood Fighting

Traffic Disruption

Figure 6: Clean Up and Debris Removal

These categories are useful when collecting and organizing damage data. Damage data are collected in post flood surveys (when investigators seek to document actual flood damages) and in damage estimates (when investigators estimate relationships between flood depths and flood damages in order to forecast flood damages).

The general working distinction between structure and contents follows a rather simple rule: If the average person would leave the item behind when moving, it is structural. Otherwise, it is content. More formally, structure damage applies to real property, content damage to personal property. The building, its utilities, permanent improvements to it like paneling, cabinets and the like as well as wall-to-wall carpeting and similar improvements are all part of structure damage. Damage to outbuildings, swimming pools, landscaping and so on are also part of structure damages.

Any other physical losses to property situated within the structure or on the grounds that are not part of the structure caused by the flood are content damages. By this definition, damages to vehicles, inventory, music collections, furniture, appliances, business equipment, and so on are examples of content damages.

In some analyses it may be useful to identify specific subcategories of structure and content damages. An investigation might, for example, report damage to landscaping (structure) or vehicles (content) separately if they are significant types of damage.

Infrastructure damage, although sometimes considered a type of structure damage, is more often a separate category. Floods may cause extensive damage to the social infrastructure. This includes physical damages to roads, gas and electric power, telephone, water supplies and conveyance systems, storm water and sewage systems, utilities, public health and safety, education, flood control structures and other critical social infrastructure.

Damage mitigation or flood fighting costs include the value of all resources used immediately prior to the flood in an effort to minimize or limit the extent of flood damages. These include the costs of moving or removing personal property, sand bagging, securing property, rescue work, preventive maintenance and so on. Labor resources are usually a great part of flood fighting costs.

Not all damage to real or personal property is physical. Other losses that can be monetized have come, for better or worse, to be called net income losses. When normal economic activities are disrupted by flooding, businesses may lose profits. To include such losses among the tangible flood damages two conditions must hold. First, the profits must be lost and not simply postponed or transferred to other firms. Second, the profits must be economic profits and not accounting profits (see Figure 7 below). Please note that the interpretation of "transferred" and "postponed" often require judgment decisions.

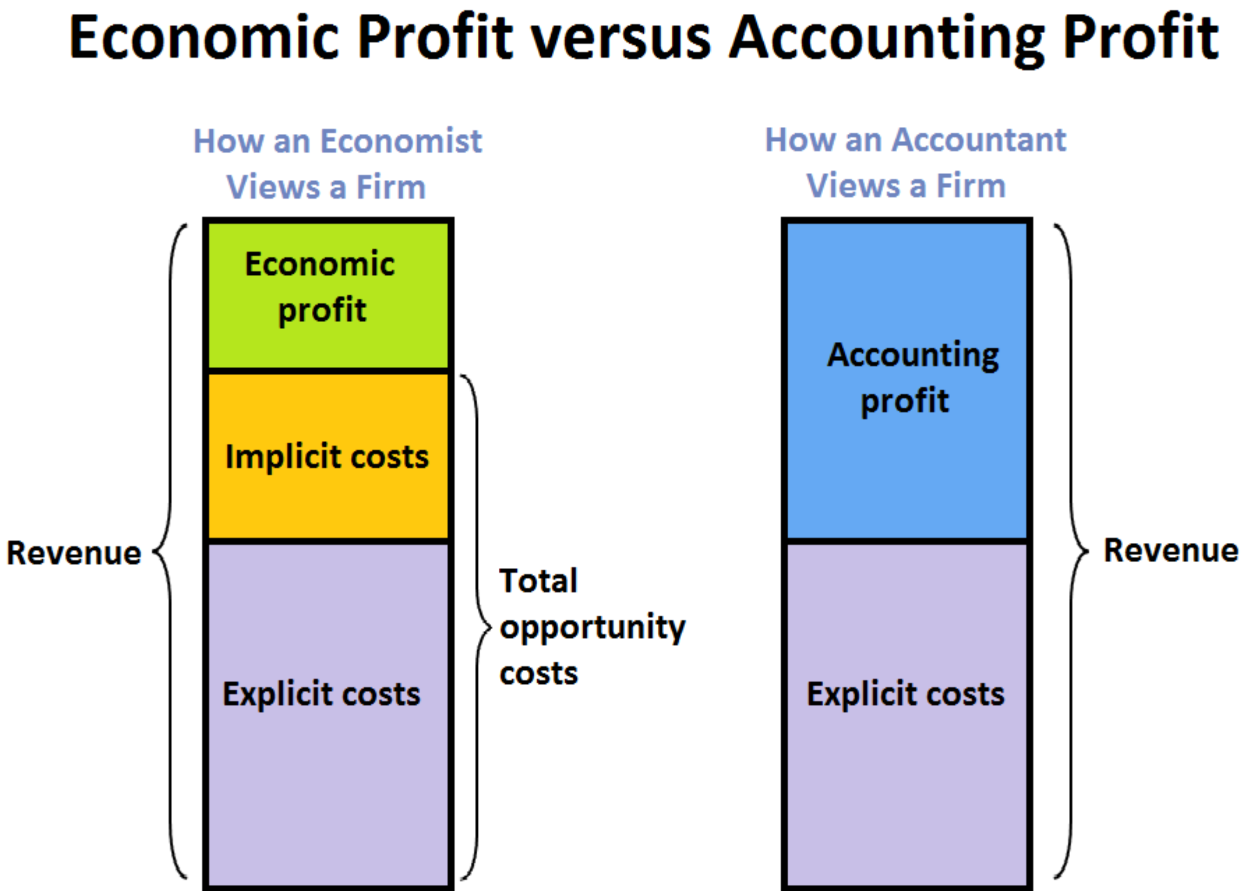


Figure 7: Comparison of how an Economist and an Accountant view a firm

By definition, accounting profit and economic profit are different in that accounting profit does not consider implicit costs (the opportunity costs). Profit from an accounting perspective is equal to total revenue minus explicit costs (total operating costs); From an economic perspective, on the other hand, profit is equal to total revenue minus explicit costs and implicit costs (opportunity costs). Economic analysis in the Corps typically studies economic profit because it reflects a more inclusive understanding of what the total costs and benefits of a project will be.

Consumers can incur income losses if they are out of work for some period of time as a direct or indirect result of flooding. The loss is the value of the labor resource, which is the associated income in a competitive market. As with the loss of economic profits, the analyst must assure that the loss is not a simple postponement or transfer. A second issue is the avoidance of double-counting. If the employee's income loss has already been accounted for by the employer it cannot be counted again.

Traffic disruption can be a major source of tangible damages. The 1993 Flood of the Mississippi River disrupted rail, barge and highway traffic for an extended period of time. The cost of traffic disruptions caused by flooding is equal to the value of the resources required to use alternative modes of transportation or routes for the disrupted traffic. This can include increased fuel costs, increased wear and tear on equipment, and the value of the time spent in longer routes.

Clean up and recovery costs include the cost of all labor and materials associated with cleaning up flood debris and damage, repairing damages, replacing evacuated and moved property, providing emergency food, water, shelter and medical expenses, policing and securing damaged areas, clearing roads, disposing of debris and other similar expenses.

The tables below (Table 1) reflects the classification of flood damages by land use category and damage type contained in ER 1105-2-100.

Physical Damages							
	Buildings	**Contents**	**Automobiles**	**Outside property**	**Landscaping**	**Infrastructure**	**Cleanup**
Residential							
Commercial							
Industrial							
Institutional							
Public							

Nonphysical Damages		
	Income losses	**Emergency costs**
Residential		
Commercial		
Industrial		
Institutional		
Public		

Table 1: Physical vs Nonphysical Damages

1.5 Flood Damage and Land Use

The previous sections presented evidence of a significant and ongoing flood damage problem in the U.S. At this point we begin to examine the nature of the flood damages that form the basis for physical damages to property.

The problem is quite simple at its most basic level. Lands that are naturally subjected to periodic inundation by floodwaters and storms are also attractive to humans for a variety of uses. The use of land by humans places plant, animal, and human life, health and property at some risk from flooding.

One of the most important elements of a flood protection benefit analysis is a good knowledge of the existing land use. This includes land at direct risk of flooding and land that is dependent on the activities that take place in flooded areas. More will be said about these issues in subsequent sections of the manual. For now, it is sufficient to understand the different kinds of land use because each type of land use has its own unique damage characteristics. When land use changes have the potential for affecting the flood problem under investigation, it is necessary to project changes in future land use by category. Some typical land use categories follow.

Buffer

A buffer is a transitional area used to separate land uses that are not naturally compatible. Buffers are often green space, but they can also contain structures (for example, neighborhood commercial land uses may effectively act as a buffer between industrial to residential land uses).

Central Business District

The Central Business District (CBD) or downtown is often a specially designated land use, characterized by a mix of dense urban development. It includes high density office, high-rise office and commercial services buildings in the heart of the city as well as a variety of retail, institutional, tourism-related and residential uses which provide services to the entire city and the metropolitan region. These areas may also serve important national and international functions.

Neighborhood Commercial

This category includes small-scale retail or service operations that serve the surrounding residential area and have limited impact on the surrounding area in terms of traffic, parking and hours of operation. Examples of neighborhood commercial include convenience stores, barber and beauty shops, general retailers, specialty shops, boutiques, art galleries, small grocery stores, gas stations, pharmacies, drug stores, banks, bakeries, specialty food, restaurants, sandwich shops, coffee houses, movie theatres, entertainment spots, hotels/motels, health and fitness clubs, personal services, print/copy shops, video rentals, dry cleaners, auto dealerships and the like.

Regional Commercial

This category includes large-scale retail or service operations that draw from outside the neighborhood and potentially bring heavier impact in terms of traffic, parking and hours of operation. Examples of regional commercial include shopping centers, downtown commercial districts, large department stores, grocery stores, big box stores, factory outlets and the like.

Industrial

This land use category describes uses of land devoted to manufacturing, processing, warehousing, packaging or treatment of products. The category is usually divided into sub-categories differentiated by the intensity of operations on the land.

Heavy Industrial

This category is characterized by manufacturing and processing operations that produce relatively high levels of noise, vibration, dust, smoke or pollution or that include outdoor storage.

Light Industrial/Office

This category is characterized by warehouses, distributors, research and business support services and light manufacturing that does not produce high levels of noise, vibration, dust, smoke or pollution and does not include outdoor storage or intensive activity. Examples of office and light industrial uses include general offices, light manufacturing, warehousing and distribution, research laboratories, prototype and production plants, automotive repair and bodywork, trade schools, auto dealers with display and lot storage/inventory and so forth.

Institutional

This category covers public operations such as schools, colleges, hospitals, daycare centers, government buildings, major sports facilities, churches, places of worship, cemeteries, hospitals, water treatment facilities, community centers, libraries, municipal buildings, post offices and so on.

High-Density Residential

Examples of this use include single-family attached dwellings (such as townhouses) as well as multifamily condominiums and apartments, at densities of 8 or more units per acre, typically about 2 to 5 stories. Densities above 18 to 25 units per acre may require some reliance on structured parking to achieve the density. These uses often include some amount of central outdoor public space for their residents, such as a pocket park.

Medium-Density Residential

Examples of this use include housing densities between 3 and 8 dwellings per acre and can include a mixture of dwelling types including single-family detached and semi-detached units, single-family attached units, patio homes, duplexes and triplexes, and townhouses. Multifamily housing is possible when using a clustered/conservation development design that preserves large portions of the site as permanent open space, although the overall density should not exceed 8 dwellings per acre.

Low-Density Residential

Examples of this use include single-family detached residential dwellings with density ranges from 1 to 3 dwelling units per acre and lot sizes typically ranging from approximately 10,000 square feet to 1 acre. Smaller lot sizes and perhaps even single-family attached housing are possible when using clustered/conservation development designs that preserve large portions of the site as permanent open space, although the overall density should not exceed 3 dwellings per acre.

Very Low Density Residential

Examples of this use include single-family detached residential dwellings having lot sizes of one acre or more.

Mixed-Use

This is a hybrid land use category that encourages a flexible mix of residential, commercial and certain light industrial uses.

Parkland/Recreation/Open Space

These land uses include green space, parks, playgrounds, public waterfront areas, neutral grounds, recreation areas, golf courses, open spaces, provision of public car parking, ancillary buildings and structures required for operating and maintaining the park or open space, and land reserved for outdoor open space.

Cropland

This use includes land used for crops, idled and pasture.

Forest

This use includes private forested land as well as forest in parks, wildlife and related areas.

Land Use and Flood Damages

Land use is the most significant determinant of the damages that will occur as a direct result of a flood. It is important that analysts understand the nature and extent of the various land uses in the floodplain. Some damage estimation techniques are based on damages estimated for a typical unit of area for a particular land use. In other words, some studies will estimate damages per acre (or part of an acre) for the various commercial, industrial and residential uses found in the urban floodplain.

Harris County, Texas: An Example

Harris County, Texas is the third most populous county in the U.S. with 3.5 million people. It encompasses the City of Houston. The Harris County Flood Control District provides one of the most informative web sites available for local flooding problems. The site is well worth a little time for anyone who is relatively new to the study of floods and flooding.

The maps below (Figure 8 and Figure 9) show the beltway highway systems that encircle the City of Houston. All of the urban land uses discussed above is found in ample measure in Harris County. The first map illustrates the different kinds of flood plains; and therefore also illustrates the flood problems that affect Harris County. The map on the bottom illustrates the extent of floodplain land in the county. These maps of just one county in the U.S. provide an excellent illustration of the extent of the flood problems in the U.S.

Tropical Storm Allison in June, 2001 dumped as much as 80 percent of the area's average annual rainfall over much of Harris County. The flooding that resulted directly affected more than 2 million people. The storm and its flooding caused 22 fatalities, 95,000 damaged automobiles and trucks, 73,000 damaged residences, 30,000 stranded residents in shelters and over $5 billion in property damage in Harris County alone. Before Allison was finished, 31 counties in Texas, 25 parishes in Louisiana, 9 counties in Florida, 5 counties in Mississippi and 2 counties in Pennsylvania were declared disaster areas. Allison was the costliest tropical storm in the history of the U.S.

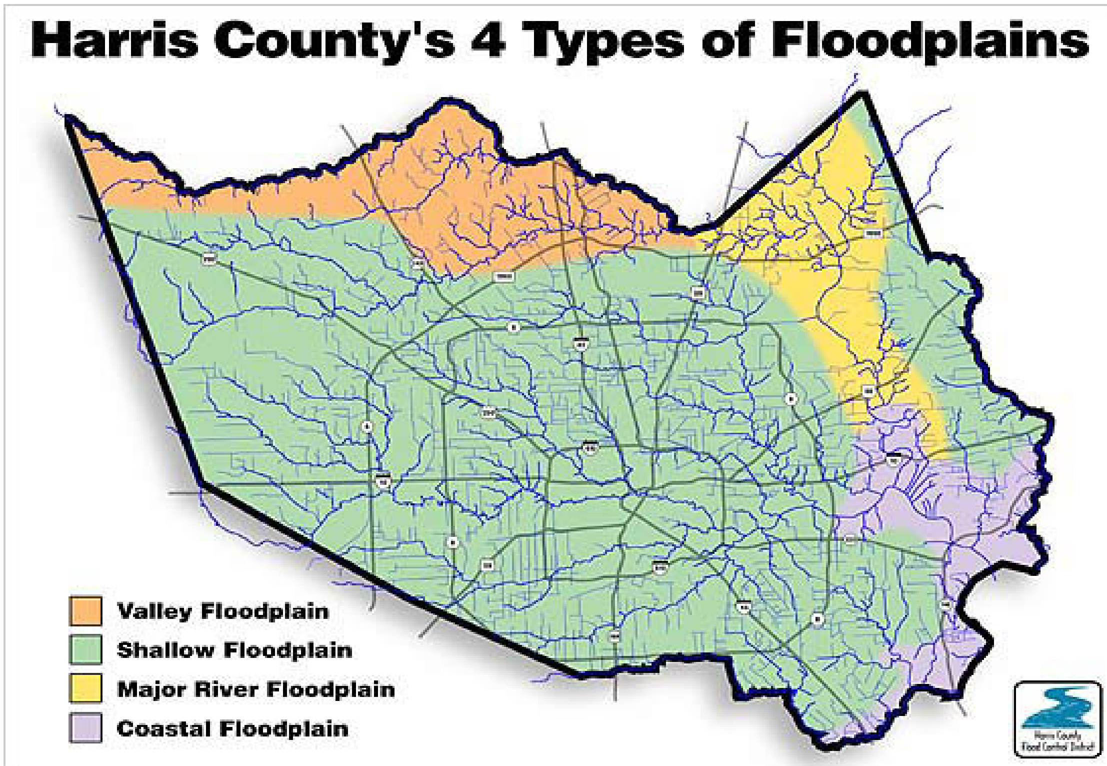


Figure 8: Harris County's Four Types of Floodplains

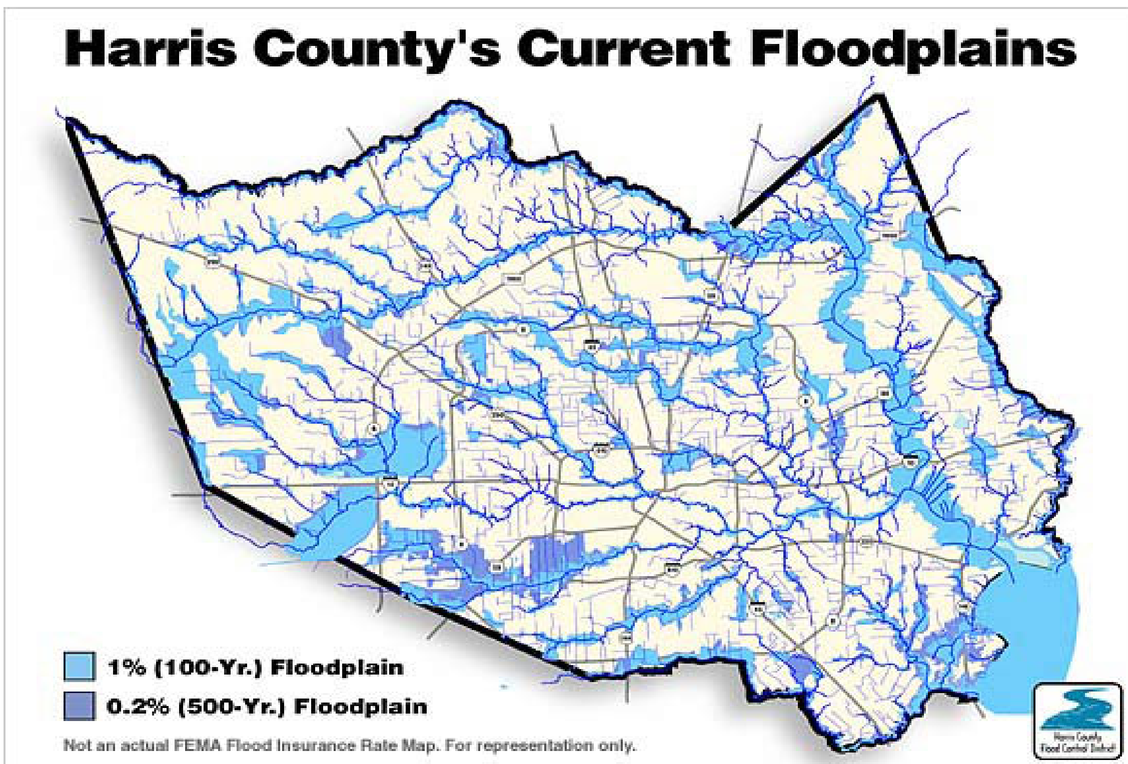


Figure 9: Harris County's Current Floodplains

For a good introduction to some of the alternatives available for flood damage reduction, see Flood Damage Reduction Tools (this is nicely illustrated with photographs of channel modifications, detention reservoirs and other flood damage reduction measures). Be sure to see the Floodplains Explained section if this is a new concept for you. The Floodplain Types provides an excellent animation that explains the types of flooding that will be encountered in many urban areas.

Land Use in the United States

Most of the United States' nearly 2.3 billion acres are not urban land uses. Figure 10 below summarizes major land use categories for the U.S.[4]

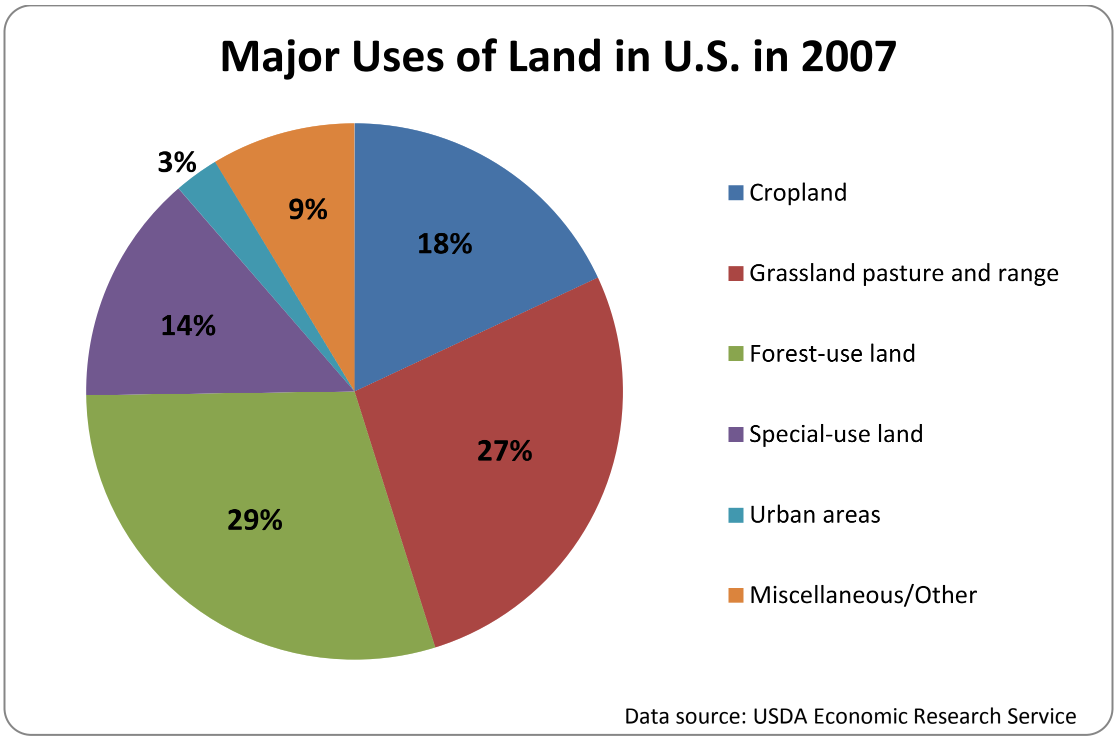


Figure 10: Major Uses of Land in the U.S. in 2007

[4] Source: USDA ERS, Major uses of land, 2007 and Major Uses of Land in the United States, 2007.

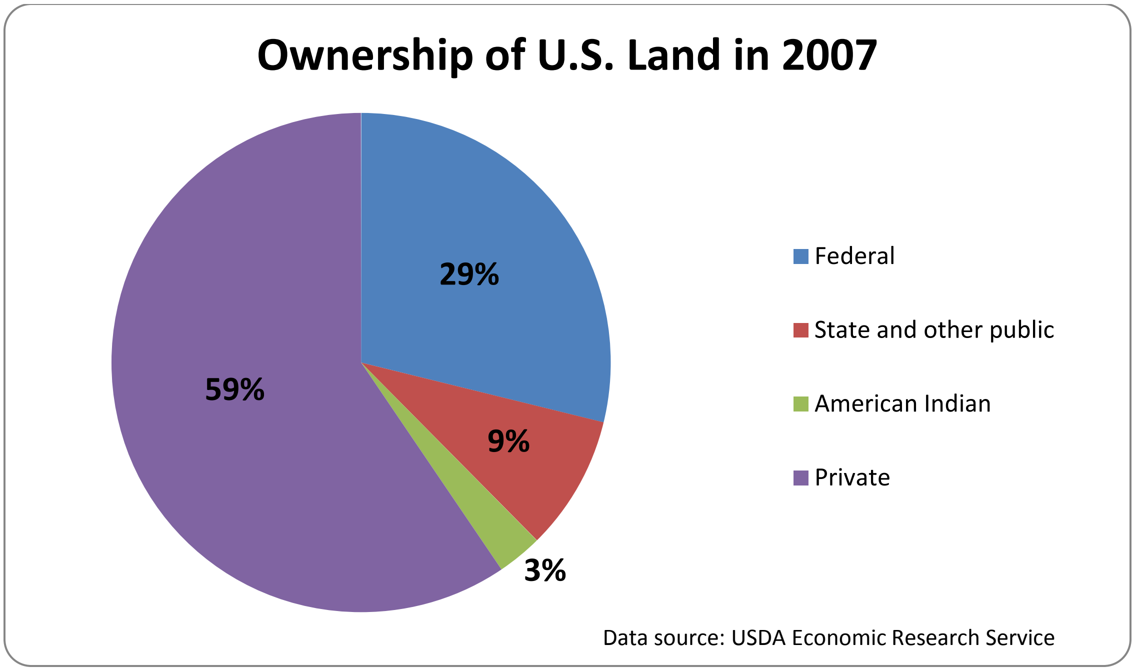


Figure 11: Ownership of U.S. Land in 2007

Most land in the U.S. is privately-owned but government holdings are substantial. Floods and land use differences give rise to substantial flood damages throughout the U.S. (see Figure 11).

1.6 Selected Flood-Related Policies

- Civil Works Engineering Regulations and Engineering Circulars
- Flood Damage Reduction Measures in Urban Areas
- Planning Community Toolbox
- Planning Community of Practice
- Planning Guidance Notebook
- Studies must comply with Executive Order 11988 (per page 36 of ER1105-2-100) and minimize adverse impacts associated with construction in the floodplain. Implementation of this EO is covered in ER 1165-2-26.

Flood damage reduction studies must be risk-based (per page 36 of ER1105-2-100). The analysis must quantify uncertainty and risk; see the entire: Risk Analysis for Flood Damage Reduction Studies.

Chapter 2: Expected Annual Damages

2.1. SMART Planning

This manual was written prior to the SMART Planning initiative; however, some small changes have been made in the text to address this new paradigm. At the time of this publication, guidance on SMART planning was being updated routinely. Therefore, the reader of this manual should check the Planning Community Toolbox for the latest tips, tool, techniques and guidance that could impact this manual's content.

2.2. What is Flood Damage Reduction Worth?

Flood damage reduction is worth what people are willing to pay for it. In theory, willingness to pay is based on the change in consumer surplus and producer surplus that results from a decrease in flood damages. These changes are areas under the demand and supply curves associated with reduction in flood damages. Changes in willingness to pay and profit would theoretically be estimated by measuring areas under supply and demand curves, but because supply and demand curves for flood damage reduction are unknown, changes in profit and willingness to pay are typically estimated by changes in income. To view a few slides that explain this concept further, click here.

As a result of the conceptual obstacles involved in directly measuring the value of flood damage reduction projects, surrogate measures of willingness to pay have been developed. Chief among these is the change in expected annual damages (EAD) that results from a flood damage reduction project. To see how EAD relate to consumer surplus, click here.

The basic idea behind this measure is that a floodplain occupant would be willing to pay no more than the value of the damages reduced by a flood damage reduction project in order to obtain the protection provided by the project. If the project costs more than the value of the reduced flood damages, it would be cheaper to bear the damages. If the project costs less than the damages it prevents, it would be cheaper to build the project.

Using the changes in expected annual damages as a proxy measure of willingness to pay requires assumptions. We assume all individuals in the floodplain are risk neutral, i.e., no one would be willing to pay more or less than the value of the damages prevented. Floodplain occupants are assumed to have perfect knowledge and understanding of complex hydrologic, hydraulic and economic relationships. They are assumed to be rational; meaning, in this case, that their solitary goal is to maximize their own utility. Although these assumptions may not be realistic for all individuals in the floodplain, they are not unreasonable constraints to place on decision makers who are acting in the role of custodians of society's resources for present and future generations. Without these assumptions, the models would be extremely complex – making them difficult to calculate and interpret.

The change in expected annual damages at best approximates true willingness to pay for flood damage reductions. Although this measure does have its limitation, it is the best method currently available for estimating flood damage reduction benefits.

2.3. Measuring Flood Damage

To illustrate issues related to measuring flood damage, let's consider an example. A television is destroyed in a flood. It cost $700 when it was new 13 years ago. It was given to the floodplain occupants by their parents at no cost when it was 10 years old. The family would have sold it for $150. It would cost $500 to get a television like it today, except today's model would have features and quality the lost TV never had. Besides, the family would prefer a big screen high definition TV now or maybe a nice plasma TV. The insurance company will allow $75 for the TV. What value should the analyst use to estimate the value of the flood loss?

Do we take the $700 then depreciate it 13 years? Do we value it as $0 because that is what the occupants paid for it? Do we use the $500 cost to replace it or the $150 they would have accepted for it? Should we adjust the $500 replacement cost to reflect the improvements in the new TV? Is the $75 book value the loss? None of these is the answer for a flood damage estimate.

The value of the television is what a buyer would be willing to pay for it. So the best measure of the TV's value is the willingness to pay (WTP) for it. What would the family have been willing to pay for a 13-year old television that worked as well as this one did? Most problems of conceptualizing the dollar damage associated with a flood loss can be solved by coming back to this willingness-to-pay standard. Estimating or measuring that conceptual value can often be a problem.

The need to grapple with this problem on a more regular basis is submerged in the use of standardized depth-percent damage curves. Depth-percent curves, commonly called "depth-damage" curves, are typically specific to the type of structure. The percent of structural damage is related to 1-foot depth increments which can then be multiplied by a structure's replacement value. These curves are often used in combination with a content-to-structure ratio to estimate content damages given the structural value to estimate content damages. There are several standardized curves that are available for specific structures. Whether the standardized curves have properly accounted for value or not is an important issue that is well beyond the scope of this manual. The only way to ascertain that is to examine or understand the construction of the standardized curves. It is best to ask one's division economist about these curves applicability to a given study area and to learn if any other curves from recent studies could be more appropriate.

There may be instances where analysts are unable to rely on the use of standardized curves. Unique structures and floodplain activities often require a site-specific estimate of damages. In estimating these damages it is important to adhere to the WTP principle in estimating flood damages. Thus, replacement cost for lost assets must often be adjusted to reflect the fact that replacement of a used asset with a new one may represent a betterment, and a betterment is not a flood loss.

Flood damages are estimated using a variety of software tools. In most cases, a damage survey is required to gather some of the data needed to construct a stage-damage curve.

2.4. Estimating Structure and Content Value

Estimating the value of a structure is a difficult task under the best circumstances. Rarely can analysts afford the luxury of a detailed appraisal for a structure, so shortcuts are often taken. It is even more difficult to estimate the value of the contents of a structure. Past experience has shown that it is reasonable to assume that the value of a structure's contents is related to the value of the structure itself. The content-to-structure ratio (the value of contents divided by the value of structure) is a shortcut method widely used to estimate the value of a structure's contents. Once the structure value has been estimated, the value of the contents can be deduced from the assumed ratio.

The appropriate structure value to use in estimating potential flood damages is the depreciated replacement value. As the previous discussion of what constitutes flood damage has suggested, it is not appropriate to use the cost of a new replacement as a measure of damages. This is as true for structures as it is for TV's and other personal property. The main reason why depreciated replacement value is the Corps standard is relatively simple: A brand new version of a given product is not valued at an amount equal to what the old one was worth.

Updating Cost Estimates Help - What is Current Guidance on How to Update?

Changes in price levels may occur over the lifetime of a flood damage analysis. It is not necessary to redo the analysis for relatively minor changes. In these cases, price changes may be measured by appropriate price indices or by observation of changes in particular unit prices. The indices most commonly used to update price levels are shown below.

The Engineering News Record is a privately published magazine that has maintained U.S. and regional building and construction cost indices for decades. These indices have often been used to update structure costs.

The Bureau of Labor Statistics of the U.S. Government prepares both the Consumer Price Index and the Producer Price Index. These indices and their component parts have been used to provide estimates of price level changes for the contents of residential and commercial structures.

2.5. Elevation Data

For an introduction to the basic elevation data requirements for a stage-damage curve, click here. The demonstration is automatically timed, you need only open it then click “play slideshow from beginning.”

Consider Figure 12 below. There are four houses in the floodplain. Each one sets at a different elevation. When the analyst goes into the field to survey the potential flood damages they must count and identify the structures sufficiently to match them up with a standardized depth-percent damage and to calculate a depreciated replacement cost value for each. In addition, however, some elevation data is needed for each structure. Normally, two pieces of information are needed. One is the zero damage point or ground elevation. This is the highest level water can reach without causing damages. The other is the first floor elevation. For the house on the left the zero damage point is 105.0 NGVD (National Geodetic Vertical Datum) and the first floor elevation is 113.8 NGVD.

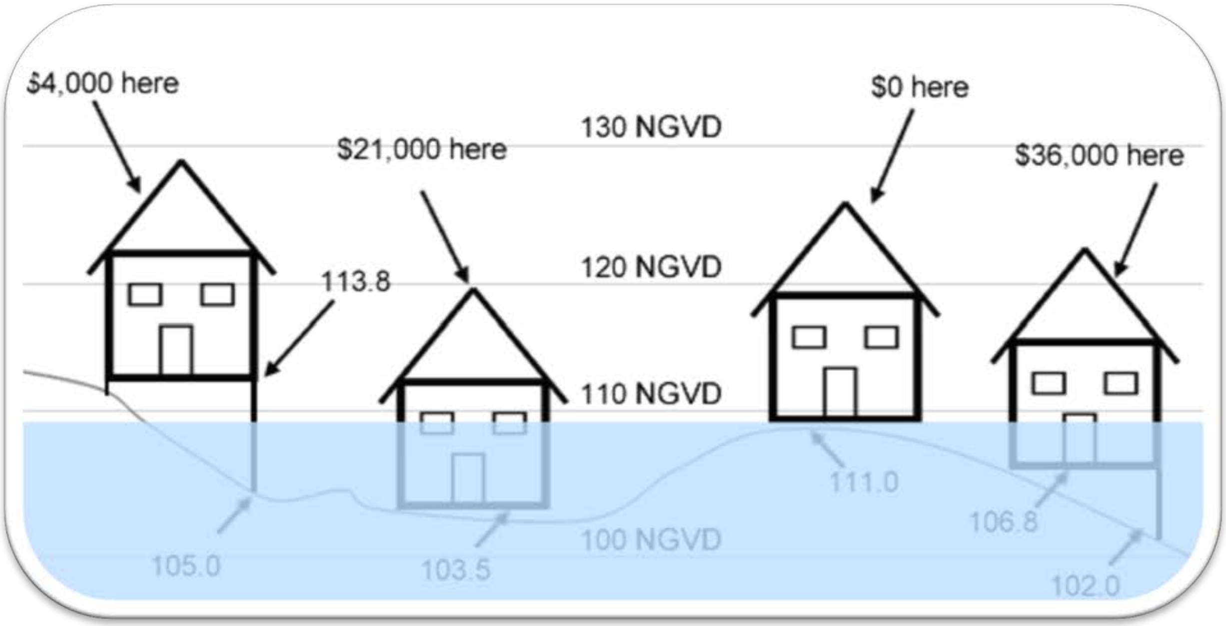


Figure 12: Four Houses in a Floodplain

Notice that the floodwaters attain a height of 110 NGVD. In this small reach of the river the water surface is flat, but the water attains a different level of flooding relative to the first floor for each structure. The graphic shows one house with $4,000 in damage and the other three with $21,000, $0 and $36,000 for a total of $61,000 in damages. Thus, 110 NGVD and $61,000 comprise one data point on a stage-damage curve for these four houses.

Actual floodplains can be much more complex of course. There are many different kinds of land use and there can be a lot of variation in the topography and water surface profile. Nonetheless, the problem remains essentially as described here. Analysts must collect the field data in a format that is compatible with the requirements of the software tools used to aid the analysis. Added, elevations can be based on various datums or years, so be sure that the datum used for structures matches what all team members are using; this will prevent a the same elevation will have the same value and calibrated to one another.

With the sophisticated tools available to assist the estimation of expected annual damages (such as HEC-FDA) the analyst usually has only to collect data carefully and in the format required. This is very convenient for the analyst because flood depths vary with the slope of the land and the riverbed itself.

Structure Data Collection Requirements:

- Location of structure (reach, address)
- Elevation of structure (topography [ground elevation], first floor elevation)
- Type of structure (single family residential, public, etc.)
- Size of structure (square footage, number of stories)
- Type of construction (wood, brick, concrete, steel)
- Condition of structure (effective age)

Figure 13: Structure Data Collection Requirements

2.6. Reaches

Expected annual damages are estimated for reaches. A reach is a length of stream or valley used as a unit of study and is usually defined on the basis of hydraulic or economic features. Occasionally a reach may be defined on the basis of political jurisdictions or a feature, such as a bridge, that requires special attention in the study. In Figure 14 below, reaches are delineated by the teal lines, the floodplain is outlined in yellow, and the floodway is outlined in white. A variety of land uses are contained in each reach.

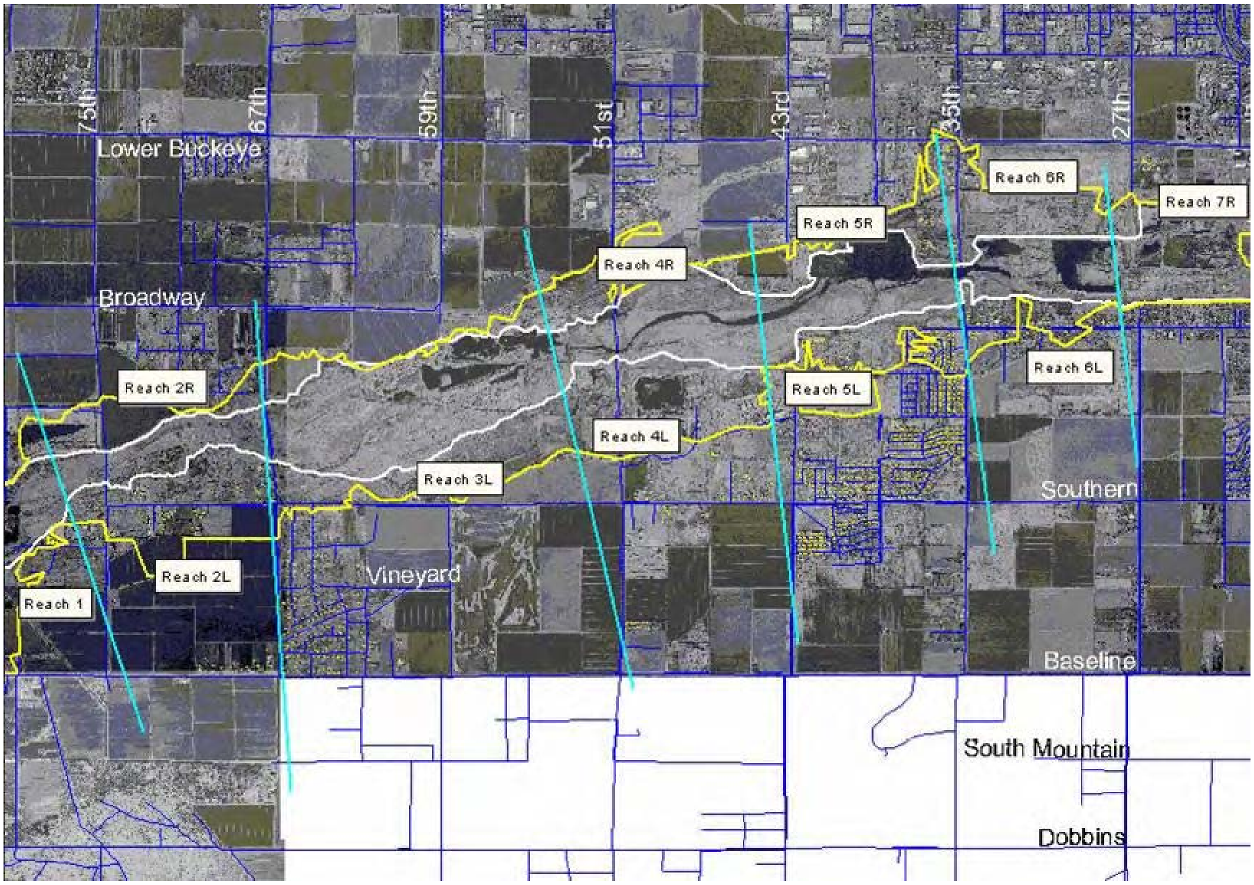


Figure 14: Reach

The Hydraulics and Hydrology - Technical References NRCS National Engineering Handbook (from which the following is taken) states that reaches are shorter for hydraulic studies than for economic ones, so it is best to consider hydraulic needs first when selecting reaches and then combine the hydraulic reaches into longer ones for the economic study. Reaches are physically defined at each end by cross sections that usually extend across the valley and include the channel section as well as a significant portion of the floodplain. The section should include enough of the floodplain to extend beyond whatever flood limits the engineer expects to occur in the study.

The *head* and *foot* of a reach are the upstream and downstream ends respectively. *Right bank* and *left bank* are designated looking downstream. For reference, reaches and cross sections are numbered in any simple and consistent way.

The purpose of a reach determines the data that must be developed from field surveys. A hydrologic study requires data regarding stage and discharge, stage and end-area and, if manual flood routings will be made, discharge and velocity. An economic study also requires data regarding stage and discharge, stage and area-inundated, and stage and damage.

2.7. The Hydro-Economic Model: How Do We Think About Flooding?

The Corps makes extensive use of a hydro-economic model (see Figure 15) to estimate expected annual damages without and with flood damage reduction measures in place. The model combines characteristics of the flooding and of the development in the floodplain to characterize the economic dimensions of the flood problem. The hydro-economic model has four component parts: the stage-discharge curve, the discharge-exceedance frequency curve, the stage-damage curve, and the damage-exceedance frequency curve. In this initial presentation of the model, these relationships are presented as if they are known with certainty. This makes it easier to understand the basic inputs and the structure of the model. The relationships will be treated more realistically in the chapters on Uncertainty.

The basic hydro-economic model used to estimate expected annual damages is shown in Figure 16 below. The model's inputs are the three relationships represented by curves in the top two and bottom left quadrants. These are the stage-discharge, discharge-exceedance frequency, and stage-damage relationships. Each of these relationships captures a unique and important dimension of the flood problem and is discussed at length in this chapter. The output of the model is the derived relationship graphed in the bottom right quadrant, the damage-exceedance frequency curve. These curves provide the theoretical construct behind the values shown in the "Simple Hydro-Economic Model" table that will be used many times throughout this manual. *(Note: When talking about flooding frequencies, it is common practice to discuss exceedance frequencies. An exceedance frequency is the annual probability that a discharge of a given magnitude will be equaled or exceeded in any given year. In the model below, exceedance frequency is a relative frequency expressed as a percentage.)* This model is consistent with EAD computation featured in EM 1110-2-1619, as well as other literature regarding flood management such as "USACE Experience in Implementing Risk Analysis for Flood Damage Reduction Projects" by Davis, et al., which was published in the *Journal of Contemporary Water Research and Education* in 2008.

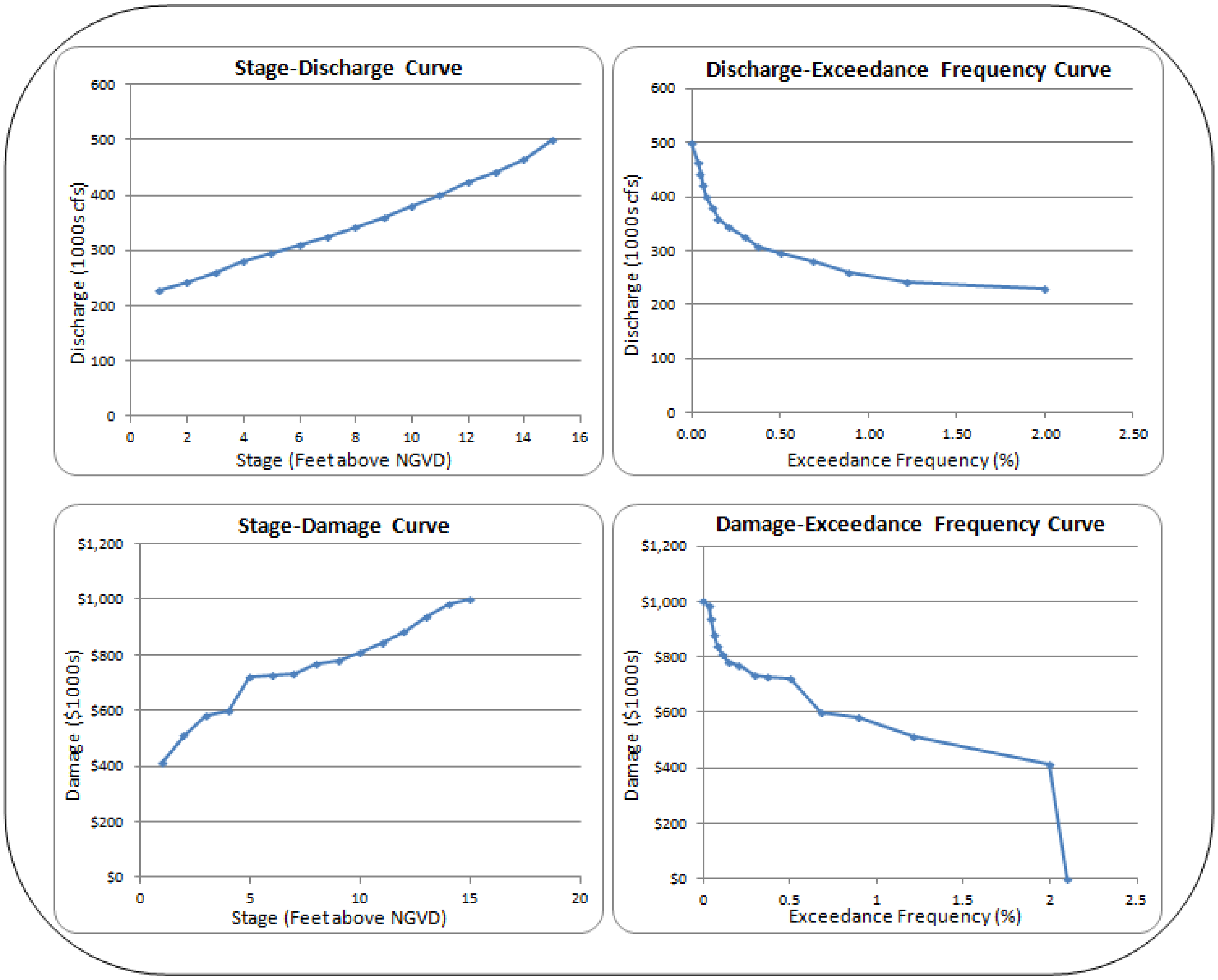


Figure 15: Hydro-Economic Model Used to Estimate Expected Annual Damages

Benefit Estimation

The area under the damage-exceedance frequency curve is the expected annual damage that exists under the conditions described by the three input relationships. "Without-condition" expected annual damages are estimated using the stage-damage, stage-discharge and discharge-exceedance frequency curves that represent conditions most likely to exist if no flood damage reduction measures are implemented. The Corps currently uses the Hydrologic Engineering Center's Flood Damage Analysis (HEC-FDA) software to estimate expected annual damages.

A flood damage reduction measure or project will alter one or more of the input relationships resulting in a different derived damage-exceedance frequency curve. The area under the modified damage-exceedance frequency curve represents expected annual damages with that particular flood damage reduction measure in place. These damages are referred to as the "with-condition" damages. It is important to be clear about the difference between (ordinary) frequency and relative frequency. Typically, when we talk about exceedance frequency, we use relative frequency – the ratio of the number of times a given event occurred to the total number of observations. Ordinary frequency, on the other hand, refers to the number of times a given event occurred.

In Corps jargon, the damages described are often referred to as with- and without-condition damages. Benefit estimates are prepared by subtracting the expected annual damages with a project from the expected annual damages without a project.

An Example

Before examining this relationship in greater detail, consider the above example illustrated in table form below. A with-project condition reflecting the impact of a floodwall or levee has been added to the example. It is the second or lower set of calculations that you see in the table below. To obtain a copy of this file, right click EAD Example. The stage-damage curve is given by Columns 2 (stage) and 5 (damage). The stage-discharge curve is defined by Column 2 (stage) and Column 1 (discharge). Notice these two relationships have stage in common. The discharge-exceedance frequency curve consists of Column 1 (discharge) and Column 3 (frequency). The discharge-exceedance frequency curve and the stage-discharge curve have Column 1 in common. The table nicely displays how simple it is to derive the damage-exceedance frequency curve from all of this. The damage-exceedance frequency curve is defined by Columns 3 and 5. They can be linked together because damages can be linked to stage which can be linked to flow which can be linked to frequency. So, in an odd sort of transitivity, damages are linked to their frequency of occurrence (their exceedance frequency). Click here for a narrated example.

Because the table below is used repeatedly throughout this manual, it is useful to take the time to fully understand the information it presents. Column 1 (discharge) shows the amount of discharge (in thousands of cfs) that corresponds with each stage. Column 2 (stage) refers to the depth of flooding. The values in this column are measured in feet above NGVD. Remember that NGVD is the National Geodetic Vertical Datum. Columns 1 and 2 together define the stage-discharge curve, which illustrates the discharge required to cause water to rise to a given height throughout the reach. Column 3 (frequency) indicates the frequency of flooding at each given stage and the values in this column are given as percentages. These values are also called the exceedance frequencies. Column 4 (change in frequency) shows the change in frequency from the previous stage to the current stage. This value is the difference in percentages since frequency is measured as a percentage. Column 5 (damages) indicates the estimated value of damages (in dollars) that corresponds with each stage. Columns 3 and 5 together define the damage-exceedance frequency curve. Column 6 (average) illustrates the average value of damages for the current and all previous stages. Column 7 (annual damages at interval) indicates the estimated value of annual damages at each interval. This value is the product of the corresponding values in columns 4 and 6. Finally, Column 8 (annual damages: summation of previous intervals) gives the cumulative value of annual damages for each given stage and the previous stages that have been estimated.

Simple Hydro-Economic Model: Benefits Accruing to Floodwall

WITHOUT-PROJECT CONDITION

Discharge (000's)	Stage (Feet above NGVD)	Exceedance Frequency (%)	Change in Frequency (% interval)	Damages (at stage)	Average (000's)	ANNUAL DAMAGES At interval (000's)	ANNUAL DAMAGES Summation of previous intervals (000's)
228	1	2.000	--	$411,980	--	--	--
242	2	1.217	0.783	$509,478	$460,729	$3,608	$3,608
259	3	0.893	0.324	$581,244	$545,361	$1,767	$5,374
280	4	0.683	0.210	$601,072	$591,158	$1,241	$6,616
295	5	0.503	0.180	$719,565	$660,319	$1,189	$7,804
308	6	0.373	0.130	$726,761	$723,163	$940	$8,745
325	7	0.298	0.075	$733,043	$729,902	$547	$9,292
342	8	0.209	0.089	$769,356	$751,200	$669	$9,961
358	9	0.150	0.059	$779,384	$774,370	$457	$10,417
380	10	0.115	0.035	$807,236	$793,310	$278	$10,695
400	11	0.082	0.033	$841,379	$824,308	$272	$10,967
422	12	0.065	0.017	$880,982	$861,181	$146	$11,114
442	13	0.048	0.017	$935,127	$908,055	$154	$11,268
464	14	0.035	0.013	$982,638	$958,883	$125	$11,393
	15	0.001	0.034	$1,000,000	$991,319	$337	**$11,730**

WITH-PROJECT CONDITION

Discharge (000's)	Stage (Feet above NGVD)	Exceedance Frequency (%)	Change in Frequency (% interval)	Damages (at stage)	Average (000's)	ANNUAL DAMAGES At interval (000's)	ANNUAL DAMAGES Summation of previous intervals (000's)
228	1	2.000	--	$0	--	--	--
242	2	1.217	0.783	$0	$0	$0	$0
259	3	0.893	0.324	$0	$0	$0	$0
280	4	0.683	0.210	$0	$0	$0	$0
295	5	0.503	0.180	$0	$0	$0	$0
308	6	0.373	0.130	$0	$0	$0	$0
325	7	0.298	0.075	$0	$0	$0	$0
342	8	0.209	0.089	$0	$0	$0	$0
358	9	0.150	0.059	$779,384	$389,692	$230	$230
380	10	0.115	0.035	$807,236	$793,310	$278	$508
400	11	0.082	0.033	$841,379	$824,308	$272	$780
422	12	0.065	0.017	$880,982	$861,181	$146	$926
442	13	0.048	0.017	$935,127	$908,055	$154	$1,080
464	14	0.035	0.013	$982,638	$958,883	$125	$1,205
	15	0.001	0.034	$1,000,000	$991,319	$337	**$1,542**

Figure 16: Simple Hydro-Economic Model: Benefits Accruing to Floodwall

Expected annual damages in the examples in Figure 16 above are highlighted in the green cells. The without-condition analysis shows expected annual damages of $11,730,000. The with-condition analysis shows expected damages of $1,542,000 annually. The difference of $10,188,000 is the measure of the benefits attributable to the plan of improvement, in this case a floodwall or levee. Listen to a narrated explanation of expected annual damages.

The table above shows that the stage-discharge and discharge-exceedance frequency curves for the with-condition example are exactly the same as the without-condition example. Compare values in the discharge and exceedance frequency columns (columns 1 and 3, respectively) between the two conditions to convince yourself of this. Notice, however, that the damages (column 5) have changed. No damage occurs at elevations below 9 feet National Geodetic Vertical Datum (NGVD). This results in a dramatic reduction in the town's expected annual flood damages as shown above. Listen to a narrated explanation of the differences between the two conditions.

Once the damage-exceedance frequency curve values have been generated, it is easy to calculate the area under the curve they define by finding the area of many rectangles and adding them. Column 4 (the change in frequency) represents the vertical dimension of the rectangle, column 6 (average damages) is its horizontal dimension. Column 7 (annual damages at each given interval) is the area of the rectangle. The rectangles are sequentially summed in column 8 and the green cell provides the total estimated expected annual damages. To better understand this process, see a sample calculation, then examine the cell formulas in the file that you can download above.

The Natural Resources Conservation Services (NRCS) approach to economic flood studies can be found at 1986 Draft National Economics Handbook and at their Economics Site. This latter site is well worth some browsing time for anyone interested in flood damage reductions and is not familiar with the NRCS approach to flood damage reduction. Economic Tools used for flood damage analysis are found at this site.

The most comprehensive description of the Corps inundation reduction benefit estimation process is found starting at page 2.3 of Risk-Based Analysis for Flood Damage Reduction Studies EM 1110-2-1619. Now, armed with this big picture background, it is time to consider the model in more detail.

2.8. Discharge-Exceedance Frequency Relationships

The discharge-exceedance frequency relationship, or frequency curve as it is most often called, provides an estimate of the annual probability that any given minimum flow or a greater one occurs in any year. A discharge-exceedance frequency curve is shown in Figure 17 below. The curve typically has a negative slope when drawn as shown; however, it can also be displayed as a positively sloped curve if the units of measure on the axes are changed.

Discharge, shown on the vertical axis, is again measured in cfs. For a given reach, the scale of the vertical axis will be identical to the scale of the stage-discharge curve's vertical axis. This common scale links the stage of the stage-discharge curve to the probability on the frequency curve. The horizontal axis shows the exceedance frequency with which a given discharge or greater occurs.

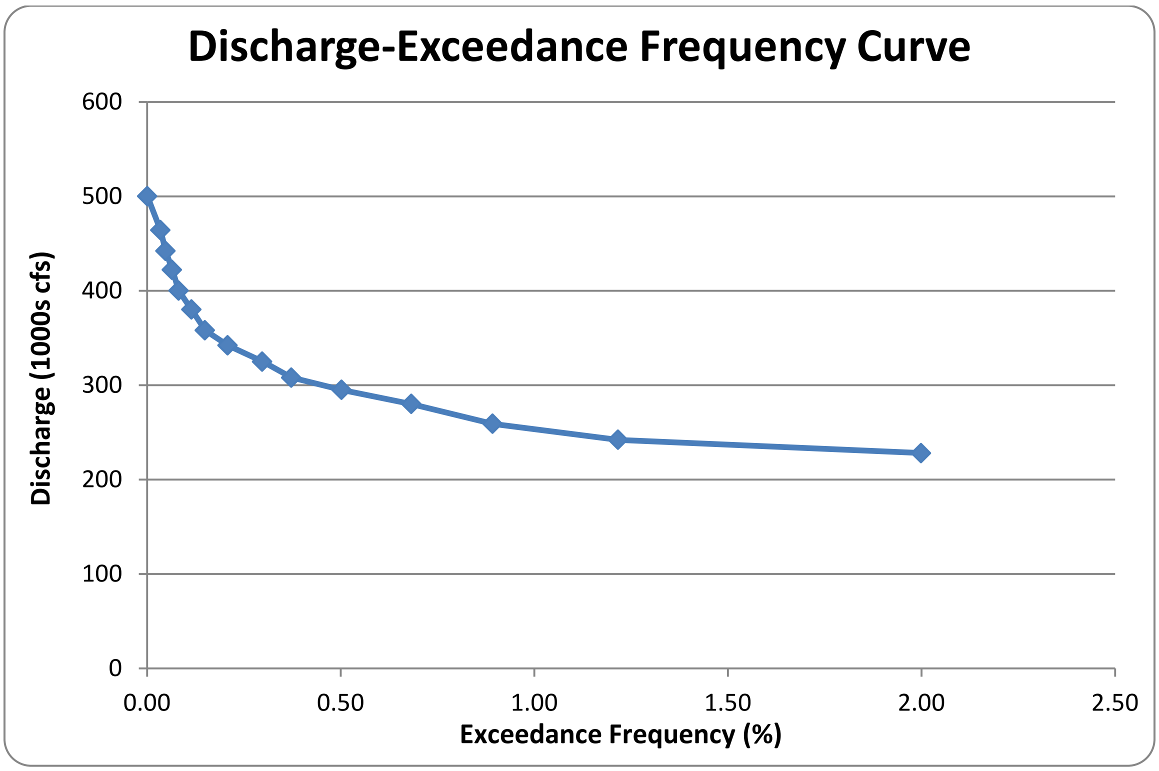


Figure 17: Discharge-Exceedance Frequency Curve

Exceedance Frequency

If we noted the largest discharge, i.e., peak discharge, to occur every day on a stream for several years the distribution of discharges might look like the one in Figure 18 below. This is a graph of peak daily flows on the Susquehanna River at USGS Station Number 1554000. Along the vertical axis are peak daily discharges.

The height of the curve indicates the relative likelihood of the given discharge occurring. Note that this is a relative frequency because it is referring to the ratio of the number of times a given discharge occurred to the total number of observations. The higher the curve, the more likely the event is to occur. The distribution shows that low flows are much more likely than high flows. The blue rectangles represent the actual data and the red overlay shows a fitted hypothetical Pearson 5 curve for convenience.

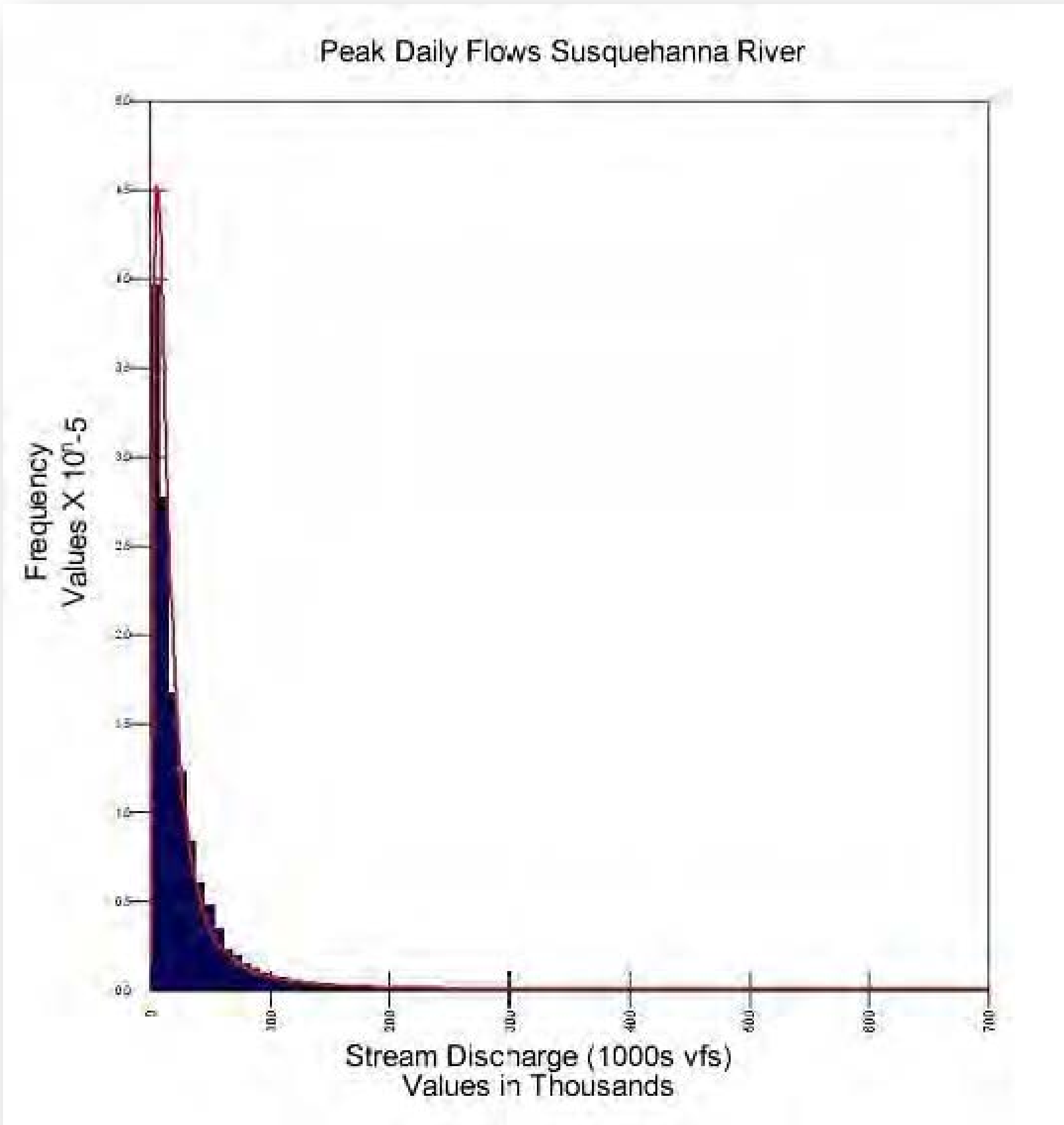


Figure 18: Peak Daily Flows Susquehanna River

The probability of a specific discharge occurring in a given year is zero. This may seem odd at first, but discharge is a continuous variable with an infinite number of possible flows so the probability of any one specific flow is but one of an infinity of values and $1/\infty = 0$. This means, as useful as it might be to have a distribution that shows all the flow data, it is not terribly useful for discussing flood events. The area under this density curve gives the probability of an event. Because the area under any one point on the curve is a dimensionless line with an area of zero, it is impossible to say anything interesting about a single discharge using this density function.

The cumulative distribution function (CDF) is far more useful for this purpose. The same data shown above are presented in their CDF format below in Figure 19.

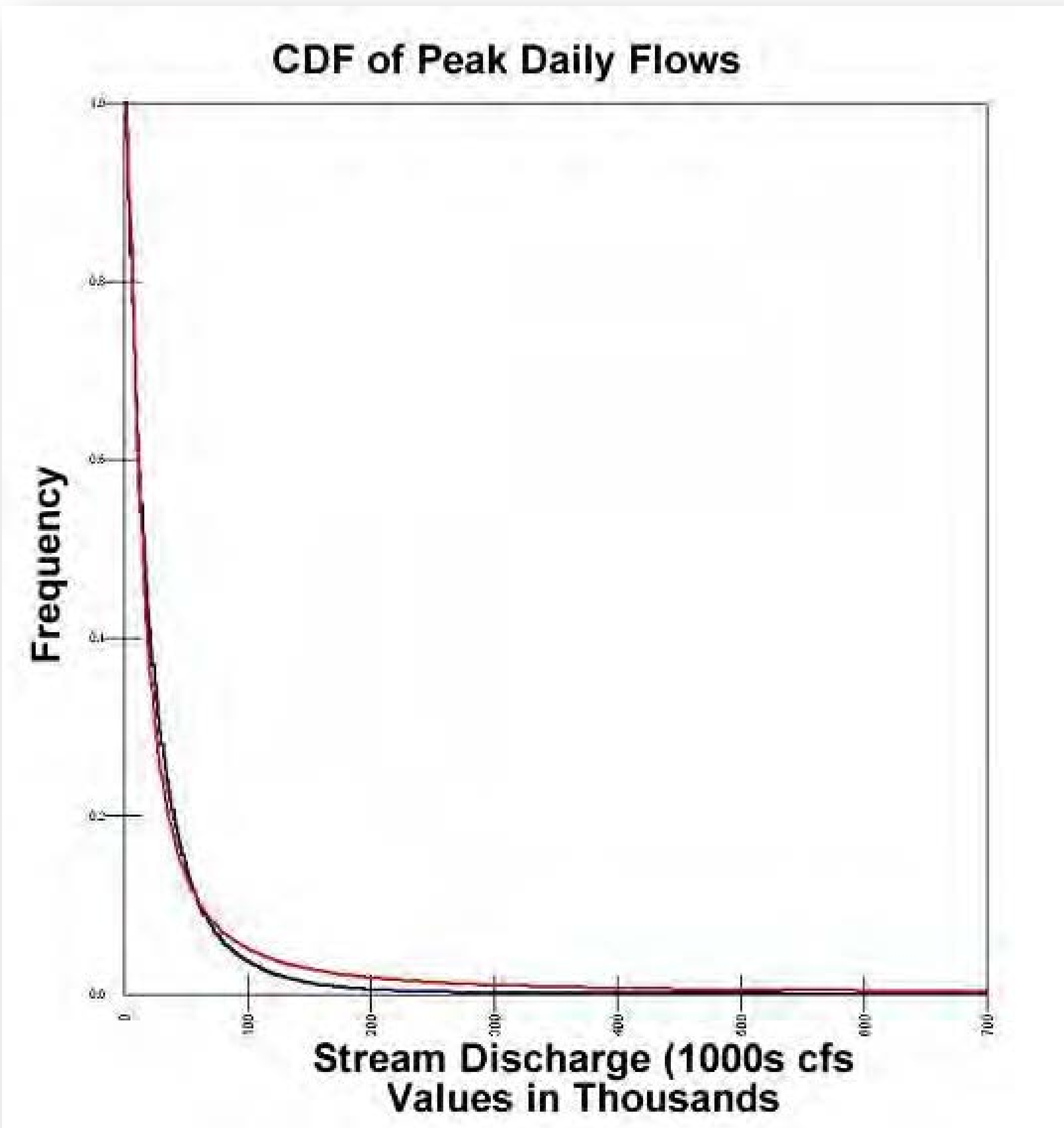


Figure 19: CDF of Peak Daily Flows

The blue curve represents the actual data, the red curve a fitted Pearson 5 distribution. This curve presents the information in a different way. Notice that the horizontal axis is stream discharge in thousands of cubic feet per second (cfs). The vertical axis is the cumulative probability. It begins at zero and increases to 100. It may be helpful to think of the cumulative distribution values as percentiles.

For example, if you locate the value 0.4 on the horizontal axis and read across to the blue curve you obtain a flow equal to 11,900 cfs. This simply means that 40 percent of all the observed flows were 11,900 cfs or less.

That means there is a 60 percent chance the peak daily flow will be more than 11,900 cfs by the complimentary law of probability. Stated differently, there is a 60 percent chance the flow will exceed 11,900 cfs on a given day.

100-Year Event

What does it mean if the annual probability of a flow of Q cfs or greater is 0.01? It means there is a 1 percent chance that Q cfs or more will occur this year. There is a 1 percent chance that Q cfs or more will occur next year, a one percent chance it will occur the year after that, and so on. If a flow of Q cfs or greater occurs this year, the probability that a flow of Q cfs or greater will occur next year is unchanged. It is still 0.01.

Consider a different sort of example. It is time to wash the dishes. Heads you wash, tails your partner washes. There is a 50% chance you will wash. The coin, a fair one, comes up heads. You wash. The next day, you flip again (still adhering to the same rules). What is the probability you are going to wash? It's 50%, same as yesterday. Does the fact that you washed yesterday affect the probability that you will wash again today? No – past results do not affect the result of flipping the coin again. Therefore, the probability of each outcome does not change and the coin toss remains a chance event.

Granted, you would not expect to wash every day. The laws of chance say, in the long run, you will win as often as you lose, but there may be stretches where you seem to be doing more than your fair share of washing. The intuition is the same for floods. If there is one chance in 100 that a flood of a certain magnitude or greater will occur in a year, over the long run you will see one of those floods for every 100 years. You might see them in back-to-back years and then not see them again for 400 years. It is all a matter of chance, of random processes.

The language of probability can be difficult. We once spoke of the “100-year flood”. One hundred years is the **recurrence interval**. The recurrence interval is the reciprocal of the probability that a discharge will be equaled or exceeded. Hence, the recurrence interval for a discharge with an annual probability of 0.01 is 1/0.01 = 100 years. It means, over a very long period of time, approaching infinity (but a million years will do nicely), we will have a discharge of that magnitude on an average of once every 100 years. That means about 10,000 of these floods will occur over a million years in any pattern at all. Like your dish washing, there may be no predictable pattern from one year to the next, but over the long run it will all average out and you will likely see about 10,000 floods of this magnitude.

While analysts know what a 100-year flood is, others believe a much more orderly and less random process was implied by the label *100-year flood*. Many people often assume that once a flood of this magnitude has occurred, they will be relatively safe for— if not 100 years — a long time. In reality, however, the chance of another flood of that magnitude remains just as likely the next year as it was the year the flood occurred. Therefore, it is now common practice to talk about the **exceedance frequency**. This is the annual probability that a discharge of a given magnitude will be equaled or exceeded in any given year.

There are many different families of distributions and discharges are generally assumed to have a **log Pearson type III distribution** rather than a normal one. The economist need not be able to conduct a hydrologic analysis, but it is essential to understand and appreciate the data and steps required to do so. The project economist and hydrologist should work in close coordination in developing without- and with-condition assumptions regarding the following: (1) future land use, (2) the operation of existing and authorized projects and the like, and (3) the determination of such things as the limits of the floodplain, reach definitions existing and future hydrology. It is essential that all analysts use the same without- and with-condition assumptions in their analyses.

The length of a reach may be determined based on water surface profiles or on the nature and extent of flood damages. The current generation of computer tools has made the designation of a reach for expected annual damage estimation purposes more a matter of convenience than of technical necessity. Now, more so than in the past, a reach is simply a length of stream that makes sense for the purposes of a particular study. In the past a reach was designated principally on the basis of its hydraulic characteristics. That need is less compelling now.

2.9. Stage-Damage Relationships

Flood damages depend on many variables. These variables might include depth of water, warning time, sediment load, velocity of floodwaters, duration of flood, water temperature, presence of waves, presence of ice, presence of toxins, time of year, time of week, time of day, topography, property at risk and many other things. Depending on the type of flood problem, some of these factors will be more important than others in determining the flood damages. For example, waves will be very important in hurricane related flooding, whereas the presence and amount of ice will be very important in ice flooding. Similarly, toxins in the water may be of great concern to people downstream of a flooded chemical plant. But one flood variable that is always expected to be associated with an increase in flood damages is the depth of flooding (also referred to as the flood stage).

The relationship is simple: as water depths increase, so do flood damages. At some point the water will be so deep as to have caused all the damage possible and the damage curve would eventually go vertical.

There is a great variety of stage-damage (a.k.a., damage-depth) relationships in use by Corps Districts around the U.S. Some Districts have developed their own curves. In the recent past, site-specific stage-damage curves had to be established for each project area. The Corps has now made generic curves available for use in two Economic Guidance Memos (EGM). These curves were developed for nation-wide use in flood damage reduction studies. If a District uses these curves, the requirement to develop site-specific stage-damage curves contained in ER 1105-2-100, E-19q.(2) is waived. Curves for residential structures with basements can be found at Economic Guidance Memo #04-01 and curves for residential structures without basements are provided in Economic Guidance Memo #01-03.

DAMAGE FUNCTIONS FOR SINGLE FAMILY RESIDENTIAL STRUCTURES WITH BASEMENTS ***Structure Stage-damage***		
Structure: One Story, With Basement		
Stage	**Mean Damage to Structure (%)**	**Standard Deviation of Damage**
-8	0.0%	0
-7	0.7%	1.34
-6	0.8%	1.06
-5	2.4%	0.94
-4	5.2%	0.91
-3	9.0%	0.88
-2	13.8%	0.85
-1	19.4%	0.93
0	25.5%	0.85
1	32.0%	0.96
2	38.7%	1.14
3	45.5%	1.37
4	52.2%	1.63
5	58.6%	1.89
6	64.5%	2.14
7	69.8%	2.35
8	74.2%	2.52
9	77.7%	2.66
10	80.1%	2.77
11	81.1%	2.88
12	81.1%	2.88
13	81.1%	2.88
14	81.1%	2.88
15	81.1%	2.88
16	81.1%	2.88

Table 2 : Damage Functions for Single Family Residential Structures with Basements

A sample curve showing the relationship between the stage, or depth, of water and the percentage damage to the structure is shown in Table 2 above. Stage is relative to the first floor (i.e., main floor, not the basement floor). Zero indicates that if water reaches the first floor the damage sustained by the structure is expected to be equal to about 25.5 percent of the structure's value. Recall that this value is the depreciated replacement value of the structure. This relationship allows the analyst to produce a stage-damage curve.

The standard deviation is used to address the variability in flood damages and/or errors in the measurement of variables used to estimate flood damages. When the water reaches a stage of 4 it is 4 feet above the first floor. The expected damage is 52.5 percent of the structure value. But damages can vary from flood to flood and structure to structure for a variety of reasons. The mean plus and minus two (actually 1.96) standard deviations is 52.2 percent plus or minus

3.2 percent. Thus, about 95 percent of all one story residences with a basement will sustain damages between 49.0 and 55.4 percent of the structure value.

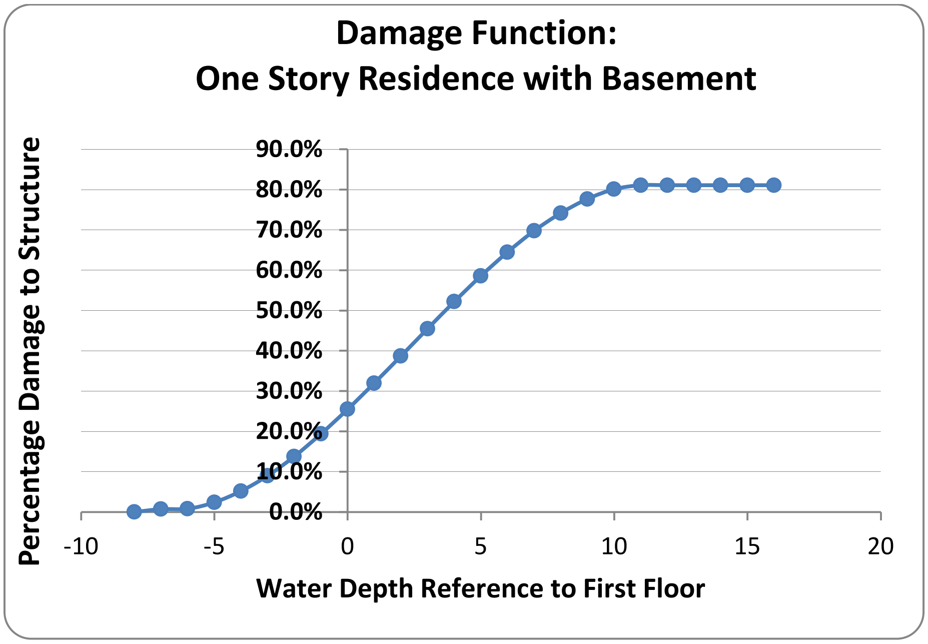


Figure 20 : Damage Function: One-Story Residence with Basement

Figure 20 above shows a graph of the mean (%) values from the previous table. These values are taken from EGM #04-01. Keep in mind that this curve represents structure damages only. Content damages are handled separately. For a few narrated observations on this curve, click here. This curve can be easily converted from a percent damage-depth curve to a damage-depth curve by including the value of the structure in the estimation of the curve. Imagine a house with a depreciated replacement value of $100,000

Look at the table above, if you change the units from percentages to thousands of dollars, you will have a damage-depth relationship in dollars.

In the past, the damages for a residential property and for some commercial properties would be estimated using a curve with depth of water and percent of damage such as this one. When a structure value was estimated, damages could then be estimated using the curve.

Damages to the structure's contents were most often estimated by first establishing the value of the structure's contents as a percentage of the structure's value. So, if the hypothetical $100,000 house had a content-to-structure ratio of 0.75 then the value of contents would estimate to be $75,000. This value would be used with a depth-percent damage curve for the contents of a house with one story and a basement to obtain a dollar damage estimate of content damage. The software used to compile these damages would then combine the two values for that one structure in order to estimate total damages. This method may still be in use in some studies.

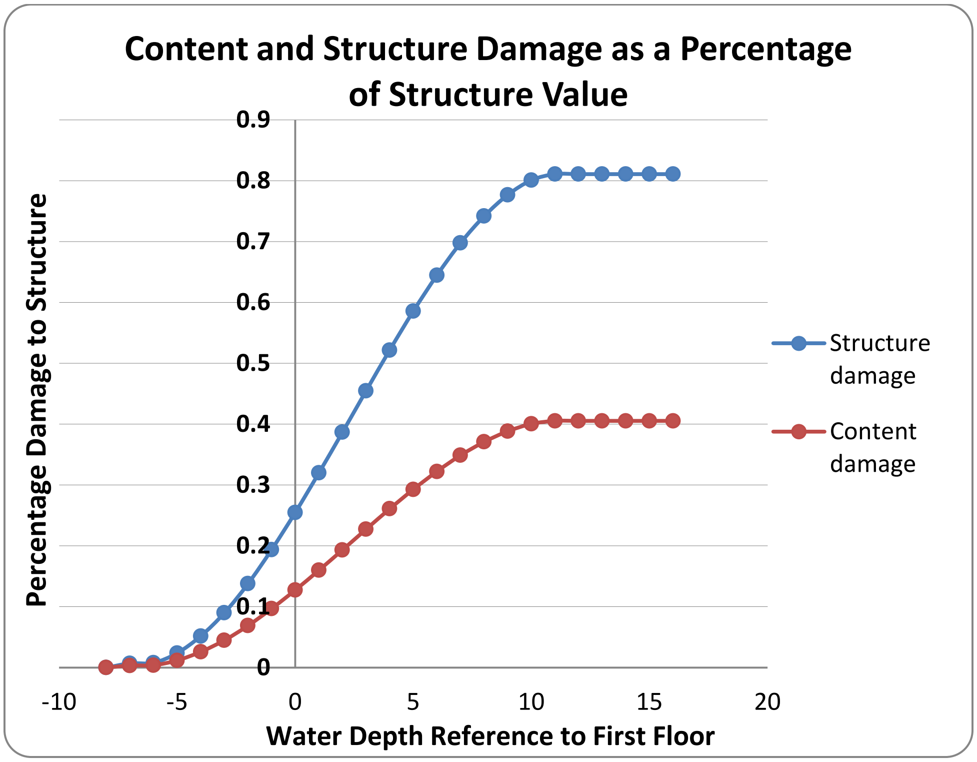


Figure 21: Content and Structure Damage as a Percentage of Structure Value

The most recent generation of damage curves approaches content damages somewhat differently. The EGM functions presented here and in Figure 21 above calculate content damage as a percent of structure value rather than an actual content value. The red curve in this figure is the content damage curve. It shows water depth and percent damage as its axes. To calculate content damage one would use the same $100,000 value used for the structure. Thus, with 4 feet of water on the first floor, the contents suffer damage equal to 27.4% of the structure's value, or $27,400. Added to the $52,200 of structure damage, this hypothetical structure sustains $79,600 in damage to its content and structure with 4 feet of water on the first floor.

The example provided here is simply one example of how damages for a structure can be calculated. The means for calculating these damages can vary between Corps Districts and even between different projects within a District.

To use one of these stage-percent (also known as depth-percent) damage curves there are at least two critical pieces of information needed: (1) an estimate of the structure's value and (2) elevation data for the structure.

2.10. Damage Survey

To prepare a stage-damage curve a damage survey or floodplain inventory must be completed. The inventory can be a census or a sample. Its purpose is to quantify the number, types and values of real and personal property at risk to various levels of flooding as summarized in a stage-damage curve.

Flood damage data may be primary or secondary data. Some examples of each include:

Primary Data

- Historical data (actual damages, post-flood reports)
- Synthetic data (experiments or detailed analysis)
- Expert opinion (interviews)

Secondary Data

- Existing data (e.g., prior studies, FEMA reports, NFIP databases)
- Similar studies (e.g., extrapolation from other locations)
- Standardized damage curves (e.g., depth-percent damage curves)

Primary Data Collection

Primary data collection requires collecting site-specific information about the stage-damage relationship. There are three ways to do this. The most common method following a flood is to gather data about actual flood damages incurred. This is the historical data approach. Its strength lie in that it is experience based and reflects real damages. Its weakness is that people learn from past experiences and unless historical damages are adjusted to reflect efforts made to reduce damages from future floods, historical damages may be irrelevant for estimating future damages.

Synthetic data can be generated by experiment or detailed analysis. Though seldom used anymore because of the expense involved, a number of past studies employed experimental methods. One of the most common methods of developing synthetic data involved assembling a team of engineers and insurance adjusters who would estimate the expected damages to structure types or items found in buildings on an item-by-item basis. This was accomplished by analyzing information on the design, materials, manufacturing, function, placement and use of structures and their contents in the floodplain as well as their susceptibility to water and sediment damage. As you can imagine, the range of items that must be evaluated can easily grow so large as to render this approach cost-prohibitive.

A more cost effective variation on the synthetic data theme is expert opinion. Under ideal circumstances this comes close to the synthetic data approach. The interviewer may ask how much damage occurs with 4 feet of water on this floor and the interviewee may possess the rare knowledge necessary to provide a detailed analysis of the structure and its content's susceptibility to flooding. The quality of the data collected with this technique varies with the expert's knowledge of their property as well as their direct experience with flooding at that location. More often than not, the expert opinion technique may be a "best guess" approach. This, however, is not bad so long as it is the "best" and the guess is an informed one.

The table in Figure 22 below shows the kind of schedule of damages by water depth (relative to the first floor of the building) that might be generated by the expert opinion approach. They are hypothetical data, say for a unique industrial building in the floodplain. The curve plots these values. For a brief explanation of the table and curve, click here.

The four numerical red data points shown in the table would be obtained from the owner of the business during an interview. Suppose a recent flood reached 2 feet (2 in the table) above the first floor of the building and caused $2,410,000 in total flood damages. What the analyst is really after is an estimate of the damages if this flood were to reoccur. For simplicity, assume there have been no changes to the property as a result of the flood. But beware that it is not always sufficient to use historical damages to estimate future flood damages, because people learn from flood events and adjust their vulnerability to damages.

Depth	Damage
-5	0
-4	0
-3	285,000
-2	**570,000**
-1	769,500
0	855,000
1	997,500
2	**2,410,000**
3	3,012,500
4	3,615,000
5	4,217,500
6	**4,580,000**
7	5,725,000
8	6,870,000
9	8,015,000
10	**7,900,000**
11	7,900,000
12	7,900,000

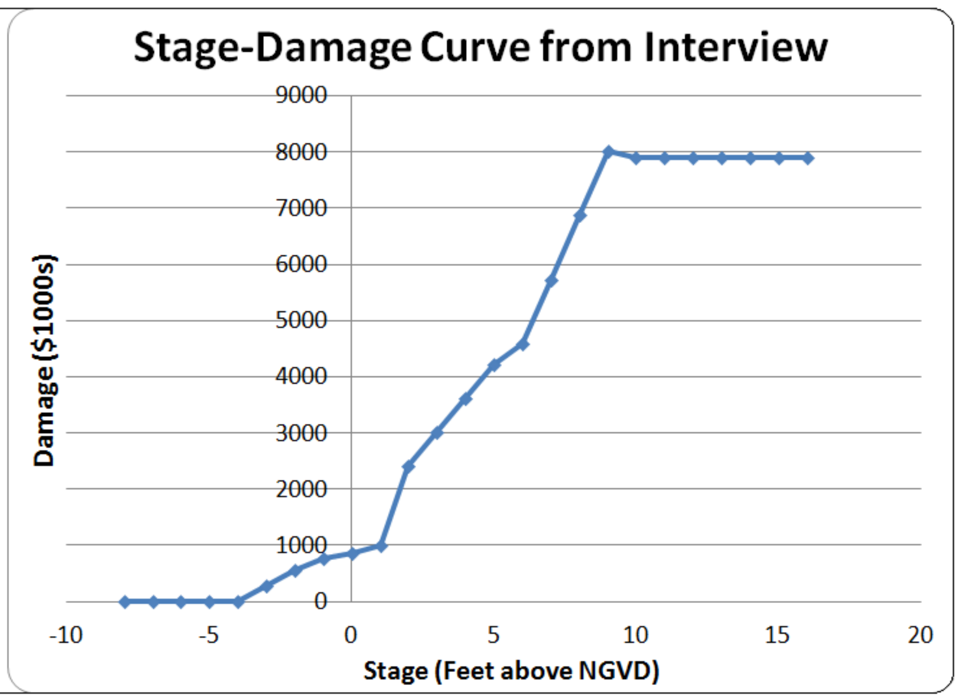


Figure 22: Stage-Damage Curve from Interview

In an actual interview it is likely that the analyst will construct one such curve for structure damages and another for content damages. In some cases it may be desirable to estimate business and other losses (flood fighting, emergency response and cleanup costs for example) associated with different levels of flooding in a third curve. The three curves can be easily summed to obtain a total damage curve for the property like the one above.

Interviews are time consuming and costly to do well. They are generally done for industrial and other unique commercial and public/institutional floodplain activities for which more standardized estimating techniques are not available.

Secondary Data Collection

A more common approach to preparing stage-damage curves is to use secondary data. There may be existing stage-damage data that was developed in earlier studies or post-flood reports for various communities. Data from related studies may be used as a preliminary guide for stage-damage relationships. For example, damage estimates based on a land area rather than on individual structures may have some utility in preliminary estimates of damages. An estimate of damages per acre of high-density residential development constructed for one analysis may be useful in a second analysis. Similar studies are useful only when seeking a rough order of magnitude estimate of the damage potential of a community for which no other data exist.

The most common method of estimating stage-damage relationships for individual properties is to use standardized damage curves. These come in two types, though one is gradually disappearing from use. These are depth-percent damage curves and depth-dollar damage curves.

Stage-percent damage curves have been developed for the most common structure types. The Institute for Water Resources (IWR) report, "Catalog of Residential Depth-Damage Functions Used by the Army Corps of Engineers in Flood Damage Estimation" (IWR Report 92-R-3) dated May 1992 provides an excellent discussion of this and related topics. "Analysis of Non-Residential Content Value and Depth Damage Data for Flood Damage Reduction Studies" (IWR Publication 96-R-12) is another good reference for this topic. The less common standardized curve is the depth-dollar damage curve. This type of curve, used more in the past that in recent years, was often developed using synthetic data generation techniques.

IWR has sponsored significant research into the development and use of standardized depth-percent damage curves. Data from the Flood Insurance Administration (FIA) was originally used to develop early standardized curves, known at the time as the FIA curves. There were FIA curves for both residential structures and their contents. The FIA curves have been eclipsed—

first, by a Corps policy that required analysts to develop curves for each study, and more recently by an improved set of stage-percent damage curves.

Summary of Steps in Developing a Stage-Damage Curve

1. Enumerate and classify each structure by building and construction type.
2. Establish the elevation of the first floor for each structure using topographic maps, aerial photographs, surveys and hand levels.
3. Estimate the value of each structure using real estate appraisals, recent sales prices, property tax assessments, replacement cost estimates or surveys.
4. Estimate the value of the contents using the structure value combined with an estimate of the contents-to-structure value ratio for each particular structure type.
5. Estimate the structure damage at various water depths for each building by combining the value of structure with a depth percent damage curve for that building and construction type.
6. Estimate the contents damage at various water depths for each building by combining the value of contents with a contents depth percent damage curve for that building type.
7. Determine the depth of water at each location by combining the elevation of a reference flood at the location with the elevation of the first floor of the structure.
8. Aggregate estimated damages at all locations for the reference flood and repeat for all other floods.

2.11. Stage-Discharge Relationships

The stage-discharge relationship, or rating curve as it is also known, shows the discharge required to cause water to rise to a given height throughout the reach. Alternatively, it shows the height to which a given discharge will rise. For an introduction to the rating curve, click here.

Discharge is the rate of flow or volume of water flowing passed a fixed point per unit of time. The most common measure of this flow is cubic feet per second (cfs). One cfs is 448.9 U.S. gallons per minute. Stage may be measured in terms of a fixed point datum (e.g., NGVD, MSL) or a relative datum like a stream gage or a flood of record. Figure 23 below uses a fixed point datum. In the hydro-economic model it will always be measured in the same units and at the same scale as the stage in the stage-damage curve. This common scale allows the analyst to link dollar damages to discharges.

The rating curve has a non-negative slope. A steeper slope indicates a narrower floodplain. Conversely, flatter slopes generally indicate a wider flood plain. This curve, for example, shows that it takes 308,000 cfs to attain a flood stage of 6 feet above NGVD and 325,000 cfs to reach to 7 feet above NGVD.

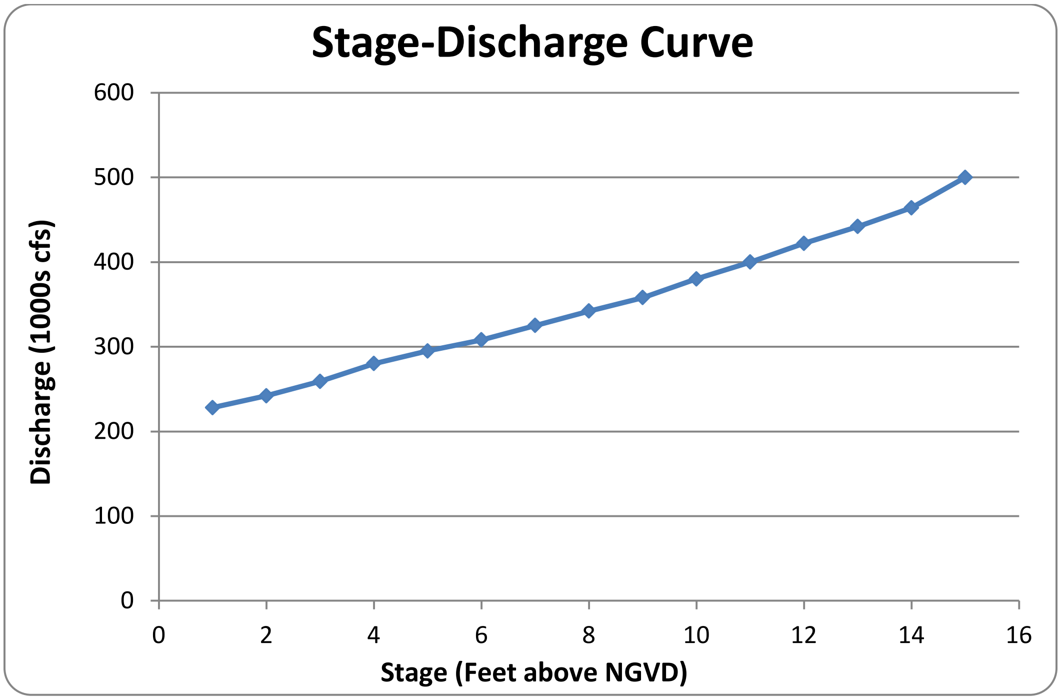


Figure 23: Stage-Discharge Curve

Constructing the Stage-discharge Curve

The stage-discharge relationship is typically developed by hydrologists and hydraulic engineers. HEC's Hydrologic Modeling System and HEC's-River Analysis System are two of the most commonly used tools for this purpose.

The methods for deriving rating curves can range from relatively simple adjustments of high water marks to match peak discharges to very sophisticated backwater computations. A typical analysis generally involves the following steps. First, historical flow data are assembled from gage records for the study area. Second, geometric measurements of stream cross sections are developed from field or remote surveys. Third, a water surface profile model is built, calibrating known discharges and elevations with the geometric capacity of the stream and adjoining flood plain. This model shows the stages a range of discharges will reach throughout the study area.

In order to reduce these tasks to a manageable level, some simplifying assumptions are often built into the programs used for these kinds of analyses. These include: (1) steady flow; (2) rigid boundary; (3) one dimensional; and (4) constant fluid properties. Steady flow means the flow rate is assumed to be fixed, so the water level does not fluctuate over the time period of interest. The rigid boundary assumption treats the cross section as stable in its geometric shape. A one dimensional system has a horizontal water surface elevation and a uni-directional flow velocity. The assumption of constant fluid properties means the sediment content of the flow does not alter the fluid properties and equations governing the model. Change any of these assumptions and there could be significant shifts in the stage-discharge curve.

In the model building phase of the hydraulic analysis, the total energy of the flow at the upstream cross section must equal the total energy of the flow at the downstream cross section plus energy losses.

Estimating energy loss coefficients is one of the more difficult tasks required to construct the water surface profile model. Manning's *n* is frequently cited as a major source of hydraulic uncertainty in the expected annual damage hydro-economic model. Manning's *n* is important in the energy loss analysis and there would be a different rating curve for each possible value. A good basic reference for the stage-discharge relationship can be found in Chapter 14 of the Hydraulics and Hydrology - Technical References NRCS National Engineering Handbook Hydraulics and Hydrology – Technical References.

The economist need not be able to conduct a hydraulic analysis; however it is essential to understand and appreciate the data and steps required to do so. The project economist and hydraulics engineer should work in close coordination in developing without- and with-project condition assumptions and in determining such things as the limits of the floodplain and reach definitions. It is absolutely essential that all analysts use the same without and with condition assumptions in their analyses.

Chapter 3: Without-Project Condition

3.1. Introduction

This topic describes the without-project condition for urban flood damage studies. It is somewhat heavy on official guidance. It begins with the Principles and Guidelines (P&G) guidance on urban flood damage benefit evaluation. The ten-step process offered by the P&G guidance, though somewhat dated, still provides a valuable framework for thinking about how to estimate flood damage reduction benefits. This process, although it is not explicitly intended to assist in the preparation of a without-project condition, is a useful guide for doing so. Please note that the terms "without-project condition" and "without-condition" (and, similarly, the terms "with-project condition" and "with-condition") are used interchangeably throughout the manual.

The without-condition is a scenario rather than a simple variable. The role of scenarios is depicted in an overview to the without- and with-conditions in the next topic, which is supplemented by the P&G urban flooding benefit evaluation guidance. This guidance relies on a comparison of expected annual flood damages without and with a project in place. For an illustrative overview of the with- and without-condition comparison process, click here (*note: this illustration uses animations in PowerPoint – simply open and click "Play slideshow from beginning"*).

ER1105-2-100 and the Without-Project Condition

The following text defining the without-condition is taken from Corps' guidance in ER 1105-2-100 (page 3-15), the Planning Guidance Notebook. This guidance clarifies important assumptions that are to be made as a matter of policy, regarding assumptions about the future in a floodplain regardless of the actual behavior of floodplain occupants. Additional policy guidance can be found later in this chapter.

Without-Project Condition. The without-project condition is the land use and related conditions expected to occur during the period of analysis in the absence of the proposed project. The following assumptions are part of the projected without-project condition:

(a) Existing flood hazard reduction plans are considered to be in place, considering the actual remaining economic life of existing structures. If there is a high likelihood of construction of a flood hazard reduction plan authorized for implementation but not yet constructed, the authorized plan is assumed to be in place.

(b) The adoption and enforcement of land use regulations pursuant to the Flood Disaster Protection Act of 1973 is assumed.

(c) For planning purposes, the Corps shall assume that communities in the floodplain belong to the National Flood Insurance Program (NFIP) administered by the Federal Emergency Management Agency (FEMA).

(d) Compliance with E.O. 11988 (described in paragraph 3-3b(1)), Floodplain Management and E.O. 11990, Protection of Wetlands, is assumed.

3.2. The P&G Evaluation Procedures (Standards Section IV)

The following sections have been excerpted (and edited in very minor ways) from the P&G for the reader's convenience. The ten steps outlined below still provide a good systematic way to think about estimating the benefits of urban flood damage projects. However, a risk management framework could also be used as seen in the Coastal Storm Risk Management NED Manual. It is important to bear in mind that future flood damages were far more significant in project evaluations at the time the P&G were written than they are now. Consequently, there is substantial emphasis on future flood damages in the original P&G material that is not as relevant now.

The ten step evaluation procedure is as follows:

1.) **Delineate affected area**
2.) **Determine floodplain characteristics**
3.) **Project activities in affected area**
4.) **Estimate potential land use**
5.) **Project land use**
6.) **Determine existing flood damages**
7.) **Project future flood damages**
8.) **Determine other costs of using the floodplain**
9.) **Collect land market value and related data**
10.) **Compute NED benefits**

Steps 1 and 2 below are as relevant as ever. Step 1 identifies the impact areas of interest for the study, recognizing the impact area may differ for different kinds of economic activity. Step 2 provides for a thorough description of the floodplain and its potential damage. This is the major part of the data collection for an urban flood damage study.

Steps 3 through 5 describe a method for forecasting increased economic activity in the floodplain or affected area(s). It is absolutely essential that project economists coordinate this work in consultation with project hydrologists and hydraulics engineers. Everyone on the study team must be using the same data and assumptions for the without- and with-project conditions. Step 3 says to obtain forecasts of population growth and other economic activity. Step 4 says convert this projected economic activity to a per acre basis.

Step 5 says to apportion this land use to floodplain and non-floodplain land in your study area. This is critically important for defining future hydrologic conditions. In Step 6 existing flood damages are estimated using some version of the hydro-economic models presented earlier for the calculation of expected annual damages. Step 7 projects future floodplain damages and this step has been changed substantially by evolving urban flood damage policy. This could include agricultural or structural damages.

Step 8 directs the analyst to consider flood costs other than those captured by the expected annual damage calculations. These potential flood losses may actually be more important than they were when the P&G were initially enacted. Step 9 directs analysts to collect market value of land data for a variety of different land use patterns with and without a flood risk reduction project. Although these types of benefits are still permissible that have been estimated with substantially less frequency in recent years and are of decreasing importance in project evaluations. Step 10 results in the estimation of benefits rarely used in urban flood damage studies. Procedures describing the federally subsidized flood insurance program are no longer applicable because the program is no longer subsidized in the same manner it once was.

Evaluation Procedure: General

Ten steps (Figure 24 below) are involved in computing benefits. The steps are designed primarily to determine land use and to relate use to the flood hazard from a NED perspective. The level of effort expended on each step depends on the nature of the proposed improvement and on the sensitivity of project formulation and justification to further refinement. The first five steps result in a determination of future land use; emphasis is on evaluating the overall reasonableness of local land use plans with respect to (a) OBERS and other larger area data and (b) recognition of the flood hazard.

OBERS projections were report that analyzed economic trends in the U.S. OBERS projections and their successor the BEA Regional Projections have been discontinued; for information see [NRCS Economics Site](); for [example projections in spreadsheet format]() download the attached file.)

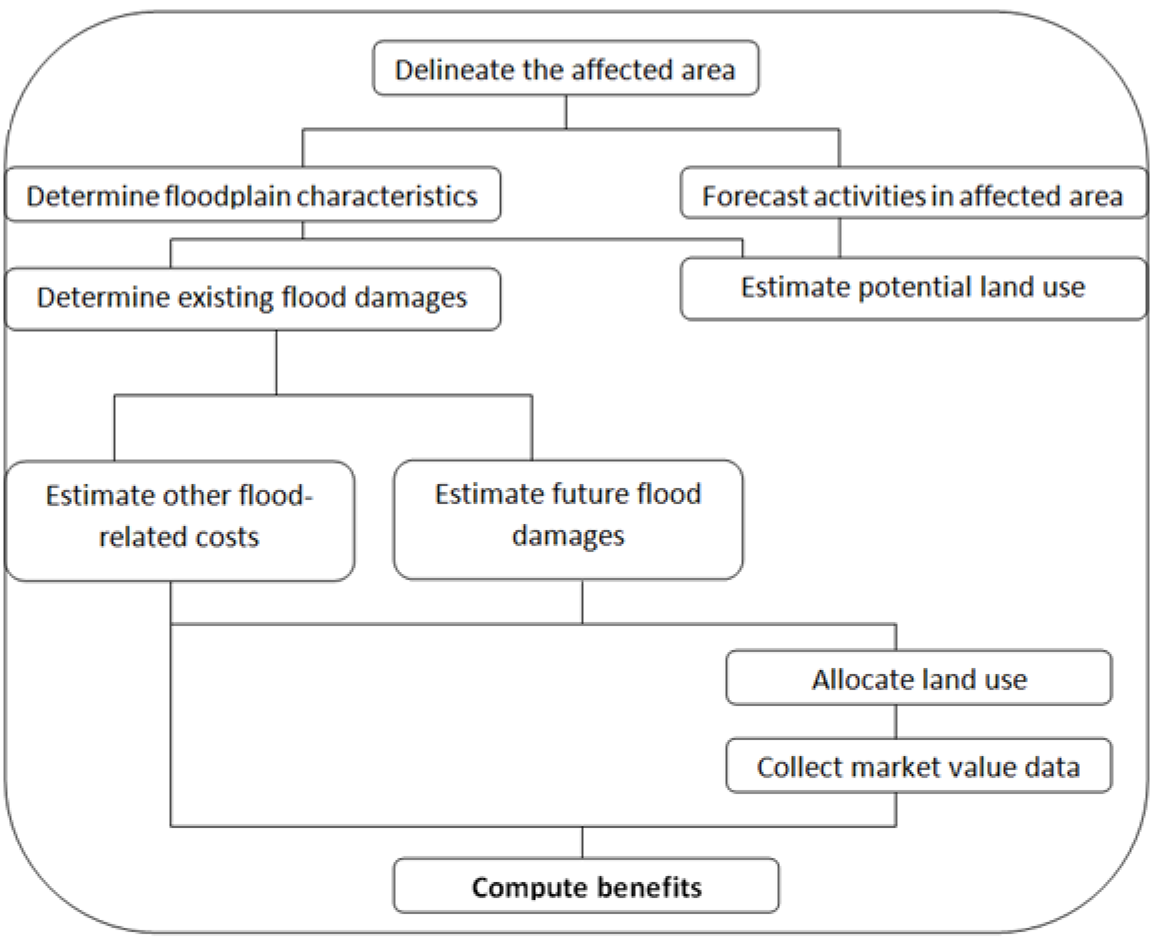


Figure 24: Ten-Step Evaluation Procedure to Compute Benefits

Step 1 - Delineate Affected Area

The area affected by a proposed plan consists of the floodplain plus all other nearby areas that are likely to serve as alternative sites for any major type of activity that might use the floodplain if it were protected; one example of a major activity-type is commercial. If the potential use of the floodplain includes industrial use within a metropolitan statistical area (MSA), the entire MSA is the affected area; for residential use, even within an MSA, a much smaller area may be designated as the affected area.

Step 2 - Determine Floodplain Characteristics.

The existing characteristics of the floodplain must be determined before its actual use can be estimated; therefore, undertake an inventory of the floodplain to determine the characteristics that make it attractive or unattractive for the land use demands established in subsequent Steps 3 and 4. Place an emphasis on those characteristics that distinguish the floodplain from other portions of the affected area. Use the following categorizations as a guide:

a. **Inherent characteristics of a floodplain.** Floodplain characteristics may include:

    1. *Flooding.* Describe the flood situation, including a designation of high hazard areas. The description should include characteristics of the flooding, such as depths, velocity, duration and debris content; area flooded by floods of selected frequencies, including 100-year frequency; historical floods and, where applicable, larger floods.
    2. *Floodway, natural storage.* Describe and delineate those areas which, if urbanized or structurally protected, would affect natural storage, velocity or stage, or would affect flood flows elsewhere.
    3. *Natural and beneficial values, including open space, recreation, wildlife and wetlands.* Many floodplains, particularly those near urban areas, are potential recreation, open space, wetland or wildlife preserves. The potential of the floodplain for these purposes should be recognized and present.
    4. *Transportation.* Floodplains near navigable streams have inherent attractiveness for industries that demand water-oriented transportation. Floodplains also serve as sites for railroads, highways, pipelines and related facilities that are not susceptible to serious flood damage but have a tendency to attract industry to the area.
    5. *Other attributes.* Other inherent attributes of floodplains may include soil fertility; reliability of water supply; waste disposal; and sand, mineral and gravel deposits.

b. **Physical characteristics.** Describe pertinent physical characteristics, including slope, soil types and water table.

c. **Available services.** Most activities require some or all of the following services: transportation (highway and rail), power, sewerage, water, labor and access to markets. Indicate the availability of such services in or near the floodplain, including comparisons with similar services available in other portions of the affected area.
d. **Existing activities.** Include in the inventory of the floodplain a list of existing activity types; the number of acres; and the density, age and value of structure for each activity-type by flood hazard zone.

Step 3 - Project Activities in Affected Area

Base economic and demographic projections on the most recent available studies and include the following: population, personal income, recreation demand, and manufacturing employment and output. Additional projections may be necessary for any given area, depending on the potential uses of the floodplain and the sensitivity of the plan to these projections. Base projections on assessment of trends in larger areas and appropriate data (e.g., OBERS); the relationship of historical data for the affected area to trends projected for larger areas; and consultation with knowledgeable local officials, planners and others. The basis for the projections should be clearly specified in the report.

Step 4 - Estimate Potential Land Use

Estimate potential land use within the affected area by converting demographic projections to acres. The conversion factors can normally be derived from published secondary sources, from agency studies of similar areas or from empirical and secondary data available in the affected area. The categories of potential land use need to be only as detailed as necessary to reflect the incidence of the flood hazard and to establish the benefits derived from a plan. One should keep in mind that future land use is assumed to be built above the 1-percent annual exceedance probability flood (formerly known as the 100-year floodplain). Therefore, no damages should occur for this event or more frequent events.

Step 5 - Project Land Use

Allocate land use demand to floodplain and non-floodplain lands for the without-project condition and for each alternative floodplain management plan.

a. **Basic factors.** Base the allocation on a comparison of the floodplain characteristics, the characteristics sought by potential occupants and the availability of sought-after characteristics in the non-floodplain portions of the affected area.
b. **Criteria.** The floodplain should not be used unless it has characteristics that give it a significant economic advantage to the potential user over all other available sites within the affected area. If such advantages exist, determine whether they

overcome potential flood losses, potential flood proofing costs and the costs of other related hazards. Flood losses and costs should be specific to the zone of the floodplain being considered.

Step 6 - Determine Existing Flood Damages

Existing flood damages are the potential average annual dollar damages to activities affected by flooding at the time of the study. Existing damages are those expressed for a given magnitude of flooding or computed in the damage frequency process. No projection is involved. The basis for the determination of existing damages is losses actually sustained in historical floods; therefore, specify the year and month of all significant recorded discharges above zero point of damage and indicate the damages actually sustained by reach or zone and type of property and activity.

Historical data are often incomplete; urbanization and other changes will have occurred over the years. Many streams and reaches do not have gauging stations. Therefore, data on historical flood losses should be carefully scrutinized and supplemented by appraisals, use of area depth-damage curves and an inventory of capital investment within the floodplain. Further, estimates of damages under existing conditions should be computed for floods of magnitudes that have not historically occurred. Estimate average annual losses by using standard damage-exceedance frequency integration techniques and computer programs that relate hydrologic flood variables such as discharge and stage to damages and to the probability of occurrence of such variables. Annual hydrologic data are normally sufficient for urban drainage estimates. Access flood damages by activity-type and by whether they are borne by the owner or by the public at large.

Step 7 - Project Future Flood Damages

Future flood damages are the dollar damages to economic activities (identified in Step 3) that might use the floodplain in the future in the absence of a plan. Use this step in combination with projected land use (identified in Step 5) in order to project each future with-project and without-project condition. *Future* refers to any time period after the year in which the study is completed; in order to relate costs ultimately to benefits, however, future damages must be discounted to the base year. Determine future flood damages on the basis of losses sustained both by the floodplain occupant and by others through insurance subsidies, tax deductions for casualty losses, disaster relief, etc.

a. **Hydrologic changes.** Changes in basin land use may result in major alteration of drainage characteristics, particularly surface runoff; project such hydrologic changes for the planning period.

Average future hydrologic conditions should not be used, since they obscure situations in which the level of protection afforded by a project may be significantly different from average conditions by the end of the planning period.

b. **Economic changes.** Economic changes can be expected to result in a change in the level of future flood losses. A benefit-cost ratio for the existing condition should always be shown. If the ratio is greater than 1:1, the projection of future benefits may be accomplished in abbreviated form unless it would distort the comparison of alternative projects or the cost allocation and cost sharing in multiple purpose projects. In the latter situation, the detail and accuracy of the estimates of flood control benefits should be comparable to the estimates of benefits for other water resources purposes.

c. **Projection of physical damages.** Base measurement and projection of flood damages on the establishment of actual, observed relationships between damages, flood characteristics and those indicators used for measurement and projection. These relationships should be modified as appropriate by consideration of constraints that change the historically derived relationship between flood damages and a given indicator. The relationships should be made explicit in the report and their accuracy and representativeness supported, to the extent possible, by empirical evidence. Use three steps in measuring flood damages for a future year: estimate the number and size of physical units; estimate the future value of units; and determine the damage susceptibility of units.

    i. *Physical units*. The first step in measuring flood damages for a future year is to determine from Step 2 ("Determine Floodplain Characteristics") the number and size of physical units with potential to use the floodplain by hazard zones for each activity type. Care must be taken to determine whether existing structures will continue to occupy the floodplain over the period of analysis and, if not, the future land use and damage potential of new structures.

    ii. *Value per physical unit*. This step involves estimating future unit value. Increases in the value of property in the floodplain may result from the expansion of existing facilities or the construction of new units. The following guidance applying to content value is derived from an empirical study of flood-prone property:

        — Existing development. Use the OBERS regional growth rate for per capita income as the basis for increasing the real value of residential contents in the future.

        — Future development. Project the value of contents within new residential structures from the year each unit is added.

- Translation to future flood damages. Use the projected rate of increase in the value of flood-susceptible household contents as the basis for increasing the future unit flood damage to household contents.

- Limit. The value of contents should not exceed 75 percent of the structural value of the residence unless an empirical study proves that a special case exists (e.g., trailer parks), nor should the increase in value of household contents be projected beyond project year 50.

- Commercial and industrial property. The procedure described for residential contents does not apply to commercial and industrial categories.

iii. *Damage susceptibility*. The third step in measuring future flood damages is to determine the damage susceptibility of units. Once the number of physical units and the value associated with each unit are known, examine possible future changes, if any, in damage susceptibility relationships as a function of the total value of each physical unit and the stream's flood characteristics. A stream's flood characteristics include variables such as velocity, depth, duration, volume, debris load and salinity. Some of the determinants of damage susceptibility are type of activity, vertical development, location within the floodplain, nature of flood proofing, construction material used and individual response.

d. **Projection of income losses.** Income losses may be projected to increase on the basis of projected land use. Increases in physical losses should not be used to project income losses. Please note that these should only be projected when the project's purposes necessitate doing so. They do not need to be used for every project.

e. **Projection of emergency costs.** Emergency costs encompass a wide variety of programs. Some, such as emergency shelter and food, are primarily a function of occupancy of the floodplain but not of the value of development in the floodplain. Emergency costs should not be projected to increase as a direct function of physical losses.

Step 8 - Determine Other Costs of Using the Floodplain

The impact of flooding on existing and potential future occupants is not limited to flood losses. Some of the impacts are intangible but others can be translated into NED losses. These latter include the following:

a. **Flood proofing costs**. High flood hazards lead to high flood costs. Therefore, compute the flood proofing costs of different activity-types and different flood hazard zones.

b. **National flood insurance costs**. A national cost of the flood insurance program is its administration. The cost of servicing flood insurance policies in effect at the time of the study is the average cost per policy, including agent commission and the costs of servicing and claims adjusting. FIA should be contacted to obtain these costs.
c. **Modified use**. In some cases, the flood hazard has caused structures to be used less efficiently than they would be with a project. For example, the first floor of garden apartments may not be rented because of a flood hazard, or property may be configured in a different way with the plan compared to without a plan.

Step 9 - Collect Land Market Value and Related Data

This step is typically not used anymore for several reasons. However, the process is laid out in this step to understand the basis of this step. An economist should check with their division economist prior to including this step in the economic analysis.

If land use is different with and without a project, compute the difference in income for the land. This is generally accomplished by using land market value data. Provide supporting data in the situations described in paragraphs (a) through (d) of this section.

a. **Land use is different with-project**. If land use is different with the project compared to without the project, collect the following data as appropriate to complete Step 10.

    1. *Comparable value*. If the plan does not result in a major addition to the supply of land in the area, the value with protection is the market value of comparable flood-free land. If the plan results in a major addition to the supply of land, the effect on the price of land should be taken into account in estimating the value of floodplain lands with protection. The flood-free land should be comparable in terms of physical and infrastructural characteristics.

    2. *Existing value*. Use the value of nearby floodplain sites or, as appropriate, the current value of the floodplain. In either case, report the current and, if available, past market values of the floodplain. Use actual market values, not capitalized income values. Therefore, it should not be assumed that the value of land being used for agriculture in an urban or urbanizing situation is the capitalized value of agricultural returns or that any value higher than that is due to speculation that a Federal program will be constructed or lack of knowledge. On the contrary, without-project land values in excess of agricultural land values should be expected, reflecting the probability of future use as well as existing and anticipated infrastructural investments.

3. *Net income data*. The net income (earned) with a project may be estimated directly based on an analysis of a specific land use with the project. This approach would be used, for example, for lands to be developed for recreation. The projected recreation benefits would constitute the gross income earned on the floodplain and would be shown as a project benefit.

4. *Encumbered title market value*. Estimate the market value of land with an encumbered title for inclusion as a benefit in Step 10 in situations in which the floodplain is to be evacuated, no specific public use is planned, and the land could be resold with an encumbered title (which would ensure that future uses would be consistent with Executive Order 11988 – Floodplain Management, May 24, 1977).

b. **Land use is same, but more intense with-project**. If land use is the same, but more intense (as when an activity's use of the floodplain is modified as a result of the project), base the determination of the increase in income on increased land values or direct computation of costs and revenues.

c. **Evacuation plan**. In the case of an evacuation plan, changes in market value of properties adjacent to a restored floodplain may reflect recreation or open-space benefits to occupants of those properties. Document such a NED benefit by empirical evidence. Care must be taken to avoid double counting of benefits.

d. **Market value is lowered by flood hazard**. If the market value of existing structures and land is lower because of the flood hazard, restoration of the market value represents a quantification of otherwise intangible benefits. In such cases, the benefit is the difference between increased market value and that portion of increased market value attributable to reductions in flood damages. Careful attention should be given to ensuring that factors not related to the flood hazard are not included as project benefits.

e. **No projected increase in market value**. Projected increase in the market value of land over the project life with and without a plan should not be used to measure flood hazard reduction benefits because the current market value of land theoretically captures the expected stream of income over time.

Step 10 - Compute NED Benefits

At this point in the analysis, enough information is available to compute NED benefits for structural and nonstructural measures. Discount and annualize all benefits at the appropriate discount rate to the beginning of the period of analysis. Benefits are categorized in the following way:

a. **Inundation reduction benefits**. To the extent that Step 5 indicates that land use is the same with and without the project, the benefit is the difference in flood damages with and without the project (Step 7), plus the reduction in flood proofing costs (Step 8), plus the reduction in insurance overhead (Step 8), plus the restoration of land values in certain circumstances (Step 9). To the extent that Step 5 indicates a difference in land use for an evacuation plan, the benefit is the reduction in externalized costs of floodplain occupancy that are typically borne by taxpayers or firms providing services to floodplain activities. Examples of such costs are subsidized flood insurance; casualty income tax deductions; flood emergency costs; and damages to utility, transportation and communication systems. Reduction of costs not borne by the floodplain activities may be a major benefit of projects to evacuate or relocate floodplain activities. Reduction of flood damages borne by floodplain activities should not be claimed as a benefit of evacuation or relocation because they are already accounted for in the fair market value of floodplain properties.

    1. *Benefit from saving insurance costs*. One category of costs that can be avoided by a removal plan is public compensation for private flood damages through the subsidized Federal Flood Insurance Program. Expressing savings in these externalized costs as project benefits is appropriate for properties in communities that participate in the Federal Flood Insurance Program or are expected to participate under the without-project condition. This benefit is the reduction of insurable flood damages projected over the life of the project with careful attention to the projected without-project condition.

    2. *Insurable flood damages*. Base the projection of insurable flood damages on traditional depth damage-exceedance frequency relationships used in projecting total flood damages. Then reduce projected total damages by subtracting: losses that are non-insurable either because they are in noninsurance loss categories or because they exceed the coverage limits of the subsidized program; the deductible portion of each expected flood damage event; and the annual cost of market value of properties, which determines project costs, reflects the availability of the program, not the extent of its utilization by current floodplain occupants.

b. **Intensification benefits**. If Step 5 indicates that land uses are the same with and without the project but activity is more intense with the project, measure the benefit as the increase in market value of land from Step 9 or changes in direct income from Step 6. Care must be taken to avoid double counting.

c. **Location benefits**. If Step 5 indicates that land use is different with and without the project, measure the benefit by the change in the net income and/or market value of the floodplain land and certain adjacent land where, for example, the plan creates open space (Step 9).

3.3. Without- and With-Project Condition Scenarios

The future will not be exactly like the past. Different plans will produce different futures. When decision makers select a plan, they are attempting to ensure a specific future. It is not a choice between now and the future, but rather a choice among alternative futures. To know which future is most desirable, the futures must be forecasted. A desirable future is one in which planning objectives are most fully achieved and planning constraints are most successfully avoided. In the process, problems are solved and opportunities are realized—this is the purpose of water resources planning.

The Corps compares the future with a particular plan (the with-condition) to the future without any action taken by the planning team to solve their problems (the without-condition). The differences between these alternative futures are described by quantitative and qualitative analyses of decision criteria important to decision makers. This process is repeated for each alternative plan formulated as a possible solution to the problems and opportunities identified by the planning team. Because every plan is compared to the same without-condition, the differences that result are due only to the differences among the plans under consideration. This process is called "with- and without-project condition analysis." And because each plan is compared to the same without-condition, it is absolutely essential to identify a good without-project condition.

With- and without-condition analysis provides a ceteris paribus (i.e., holding all other things equal) analytical framework for analyzing plan effects. This limits the effect of confounding variables on the analyses decision makers will rely upon to choose the best plan and future. In addition, with- and without-condition analysis provides the most analytically rigorous and defensible comparison technique because it focuses explicitly on the marginal differences that specific plans will make in a study area. For these reasons with- and without-condition analysis has been designated as the analytical framework to be used for water and related land resources planning by the Principles and Guidelines (P&G). Consequently, every Corps planner and Corps planning client needs to understand with- and without-condition analysis. This chapter focuses on the without-condition and the next chapter examines the with-conditions for urban flood damage studies.

The P&G on Without- and With-Project Conditions in Urban Flood Analysis

Chapter 2 of the P&G (specifically, section 2.4.3) provides the following guidance on the planning setting for urban flood damage studies.

a. **General**. The benefit of a flood hazard reduction plan is determined by comparison of the with- and without-project conditions.

b. **Without-project condition**. The without-project condition is the land use and related conditions that are likely to occur under existing improvements, laws and policies. There are three significant assumptions inherent in this definition:
   (1) *Existing and authorized plans*. Existing flood hazard reduction plans are considered to be in place, with careful consideration given to the actual remaining economic life of existing structures. Flood hazard plans authorized for implementation but not yet constructed are evaluated according to the relative likelihood of actual construction. If there is a high likelihood of construction, the authorized plan is considered to be in place.
   (2) *Flood Disaster Protection Act*. The adoption and enforcement of land use regulations pursuant to the Flood Disaster Protection Act of 1973 (Public Law 93-234) is assumed.
      a. Regulation certified or near certification. If the local land use regulation has been or will be certified, partially waived, or adjusted by the Flood Insurance Administration (FIA) as adequate under 24 CFR 1910.3 (c) and/or (d) and 24 CFR 1910.5, that regulation defines the without-project condition.
      b. Regulation not yet certified. It is assumed that the local jurisdiction will adopt (in the near future) land use regulations certifiable to FIA under the without-project condition as a datum and under the with-project condition if a residual hazard will remain. This applies to floodplains regulated under 24 CFR 1910.3 (a) and (b); to floodplains regulated by local ordinances independent of FIA; and to floodplains with no flood regulation in effect. For revenue situations, the following two crucial features are included: no future confinement or obstruction of the regulatory floodway; and no future occupancy of the flood fringe unless residences are elevated to or above the 100-year flood level and non-residences are flood proofed to that level.

c. Application. It is assumed that flood proofing costs will be incurred if an activity decides to locate in the floodplain. EO 11988, Floodplain Management and EO 11990, Protection of Wetlands, is assumed.

(3) *Individual actions*. In addition to the three assumptions stated in paragraphs (b) (1), (2) and (3) of this section, the analyst shall consider the likelihood that individuals will undertake certain flood hazard reduction measures, such as flood proofing, when e cost of such measures is reasonable compared to the costs of potential flood damages.

c. **With-project condition**. The with-project condition is the most likely condition expected to exist in the future if a specific project is undertaken. There are as many with-project conditions as there are alternative projects.

(1) In projecting a with-project condition, the analyst must be sensitive to the relationship between land use and the characteristics of the flood hazard for the alternative project being analyzed.

(2) The same assumptions underlie the with-project and without-project conditions.

(3) Consideration should be given to both structural and nonstructural alternatives and to alternatives incorporating a mix of structural and nonstructural measures. Nonstructural measures include:

a. Reducing susceptibility to flood damage by land use regulations, redevelopment and relocation policies, disaster preparedness, flood proofing, flood forecasting and warning systems, floodplain information, floodplain acquisition and easements.

b. Achieving on-site detention of flood waters by protection of natural storage areas (such as wetlands) or in manmade areas (such as building roofs and parking lots).

(4) Since project alternatives can differ in their timing as well as in their physical characteristics, the optimal timing of projects and of individual project features should be considered in project formulation.

Other Conditions of Potential Interest

There are a few other relatively common conditions that are based on inventories of available evidence. These include the historic condition, existing condition, and base year condition. This section will provide you with some insight into each of these three other conditions of potential interest.

Historic Condition

The past is sometimes important to planners because it is not easy to understand the present without some knowledge of the past. Ecosystem restoration projects often rely on knowledge of past ecological conditions in the formulation and design of alternative plans. When a scenario describing past conditions of the study area is required for a study, it is called the historic condition. There are no real guidelines for choosing an historic condition, other than that the condition must be relevant to what it was like "before” (where "before" might mean before it started to disappear). In such a case, the historic condition is nonspecific and it simply refers to a reversal of a generally recognized negative trend in an ecosystem.

An historic condition can refer to a specific period in time or to a less specific period of time. There may be instances in which a planning study might make use of multiple historic conditions. Best planning practices would always take care to define the historic condition as carefully and as precisely as possible, providing the context and purpose of the historic condition developed for the study. This would avoid the lack of clarity of expectations that can accompany the sort of vague definitions of historic conditions such as "before these problems began."

In the sense described here, historic conditions may function as a sort of target for planners to aim at in their planning efforts. Historic conditions do not usually play an explicit role in most planning investigations and would be rather rare in a single purpose urban flood damage study.

Existing Condition

The existing condition describes the criteria and other assets of interest to planners and decision makers at the time the planning study is being conducted. The time index for this condition is usually a reference period of a year or more that spans the study period, e.g., the period 2002 to 2006 may constitute existing conditions. Because the data comprising an inventory may come from many different time periods it is rare to have an existing condition that is literally from a given reference year or period. Nonetheless, the existing condition is the condition of the resources, factors and values of interest to planners at the time the planning investigation is being conducted.

There will be some elements of the existing condition that will be relatively constant over several decades or more. Geological, archeological and historical information will not change much in a few decades. In many cases, flow regimes will not be altered. But each study is likely to have elements, such as population, that may be subject to significant change over a relatively short period of time. Thus, the existing condition may need to be updated from time-to-time.

The existing condition has a rather obvious role in most planning studies: it is an obvious starting point. Developing an existing condition is an effort to objectively describe the current reality. In many Corps studies, the natural and anthropogenic conditions that give rise to the problems and opportunities of interest are dynamic. Flood problems sometimes worsen as watershed development and other changes accumulate. Channel restrictions are subject to the gradual effects of shoaling as well as the dramatic changes induced by storms. The decline of ecosystems that are being degraded can sometimes accelerate.

These examples suggest that existing conditions may not be the relevant basis for consideration and evaluation if a planning process can take ten years or more to produce solutions. Consequently, the base year condition is the more relevant condition for plan evaluation purposes and the existing condition is usually the primary input to the definition of the base year condition.

Base Year Condition

Corps planning investigations most often considers public works infrastructure and ecosystem restorations as being designed to last for 50 or more years. Therefore, Corps planning for these types of projects is different from the operational (current year) or even the strategic (three to seven years) plans of businesses that focus on much shorter planning horizons.

Water resource planners conducting a study understand that the actual implementation of a plan may be several years after the completion of the study. Thus, conditions at the time of the study may be less relevant for decision making than would the conditions at the time the project is to be completed. That “time in the future” is called the base year. The base year differs from the time during which the study is being conducted. It is the year in the future when a plan recommended for implementation can be considered operational. A plan is operational when it is either fully completed or it is completed to an extent at which it is producing the intended outputs to a significant extent.

With the structural projects of the Corps' Civil Works past, it is usually easy to recognize when a levee or reservoir will be operationally complete. With ecosystem restoration projects, some outputs may be realized early in the implementation process (e.g., removal of non-indigenous plants or reductions in salinity levels), while the intended outputs of other projects may take years after implementation to be realized. Thus, the base year is defined as the earlier of the projection completion date or the year in which significant outputs are being realized.

Base year conditions are the conditions of the resources, factors and values that are of interest to planners in the base year. The base year scenario is usually obtained by modifying the existing condition. Much of the existing condition information can be used without change, but some modifications may be necessary. For example, if habitat units are declining there may be fewer habitat units in the base year than there are at the time of the study, i.e., under the existing condition.

The base year condition describes "what will be" in a few more years. It may require a short run future forecast. It is important because the base year conditions establish a baseline for the evaluation and comparison of plans. In addition, the base year is important to the determination of the time value of money for benefit and cost calculations. (See National Economic Development Procedures Manual – National Economic Development Costs, IWR Report 93-R-12).

To see the base year concept illustrated, click here.

Without- and With-Project Condition Comparison Illustrated

The following example of a without- and with-condition comparison will illustrate how comparisons are made. The example, seen earlier in the manual, is a hypothetical and conceptual one based on real data. It shows expected annual damages if no action is taken and a reduction if a plan is implemented.

A without- and with-condition comparison, though used by the Corps, is not the only way to compare plan effects. A before and after comparison and a gap analysis are two other comparison techniques used by other interests. All of these concepts are illustrated in the attached two-slide animation. To see the conditions and their comparison illustrated, click here.

Simple Hydro-Economic Model: Benefits Accruing to Floodwall							
WITHOUT-PROJECT CONDITION							
						ANNUAL DAMAGES	
Discharge	**Stage**	**Exceedance Frequency**	**Change in Frequency**	**Damages**	**Average**	**At interval**	**Summation of previous intervals**
(000's)	(Feet above NGVD)	(%)	(% interval)	(at stage)	(000's)	(000's)	(000's)
228	1	2.000	--	$411,980	--	--	--
242	2	1.217	0.783	$509,478	$460,729	$3,608	$3,608
259	3	0.893	0.324	$581,244	$545,361	$1,767	$5,374
280	4	0.683	0.210	$601,072	$591,158	$1,241	$6,616
295	5	0.503	0.180	$719,565	$660,319	$1,189	$7,804
308	6	0.373	0.130	$726,761	$723,163	$940	$8,745
325	7	0.298	0.075	$733,043	$729,902	$547	$9,292
342	8	0.209	0.089	$769,356	$751,200	$669	$9,961
358	9	0.150	0.059	$779,384	$774,370	$457	$10,417
380	10	0.115	0.035	$807,236	$793,310	$278	$10,695
400	11	0.082	0.033	$841,379	$824,308	$272	$10,967
422	12	0.065	0.017	$880,982	$861,181	$146	$11,114
442	13	0.048	0.017	$935,127	$908,055	$154	$11,268
464	14	0.035	0.013	$982,638	$958,883	$125	$11,393
	15	0.001	0.034	$1,000,000	$991,319	$337	**$11,730**
WITH-PROJECT CONDITION							
						ANNUAL DAMAGES	
Discharge	**Stage**	**Exceedance Frequency**	**Change in Frequency**	**Damages**	**Average**	**At interval**	**Summation of previous intervals**
(000's)	(Feet above NGVD)	(%)	(% interval)	(at stage)	(000's)	(000's)	(000's)
228	1	2.000	--	$0	--	--	--
242	2	1.217	0.783	$0	$0	$0	$0
259	3	0.893	0.324	$0	$0	$0	$0
280	4	0.683	0.210	$0	$0	$0	$0
295	5	0.503	0.180	$0	$0	$0	$0
308	6	0.373	0.130	$0	$0	$0	$0
325	7	0.298	0.075	$0	$0	$0	$0
342	8	0.209	0.089	$0	$0	$0	$0
358	9	0.150	0.059	$779,384	$389,692	$230	$230
380	10	0.115	0.035	$807,236	$793,310	$278	$508
400	11	0.082	0.033	$841,379	$824,308	$272	$780
422	12	0.065	0.017	$880,982	$861,181	$146	$926
442	13	0.048	0.017	$935,127	$908,055	$154	$1,080
464	14	0.035	0.013	$982,638	$958,883	$125	$1,205
	15	0.001	0.034	$1,000,000	$991,319	$337	**$1,542**

Figure 25: Simple Hydro-Economic Model: Benefits Accruing to Floodwall

The table in Figure 25 above, shown in the EAD Chapter, supports the illustration with a numerical example. In this case the without-project condition expected annual damages are

$11,730,000. The with-project condition expected annual damages are $1,542,000. Comparing these two future conditions we see a difference of $10,188,000 in expected annual damages. This is an estimate of the benefits attributable to the project. This estimate was obtained using the same without- and with-condition comparison covered in the previous section.

3.4. Without-Project Condition

The without-condition is what results if no action is specifically taken by the Federal and nonfederal partnership created for the Corps' planning investigation. The key to understanding the without-condition is to understand what is meant by “no action”. The without-condition does not mean that no changes are made from the present. The future will be different from the present, especially when we consider a 50-year planning horizon. What the without-project condition refers to is the future that is most likely to result if the partnership between the Corps and one or more nonfederal entities decides not to take any action to address the problems and opportunities identified in its joint investigations. In other words, the without-project condition describes the study area's future if there is no Federal action taken to solve the problem(s) at hand.

It is important to understand that a forecast of the without condition does not assume an extrapolation of recent trends. The forecast may include actions taken by numerous stakeholders and other parties that could make the future look different from the existing or base year condition. Under this “no action” assumption, there may be other entities that take actions to address the problems. These could be actions taken by other governmental agencies, private businesses, individual actions or other organizations.

No one can say with certainty what the future of a study area will be like if the planning partnership takes no explicit action. The future is not knowable with certainty. Nonetheless, the Corps' current planning process calls upon planners to identify the "most likely" conditions that will prevail in the absence of any specific intervention by the partnership to solve problems or realize opportunities as a result of the planning process.

There are always many possible future conditions if no action is taken by the planning team. These conditions must be forecasted and the most likely of them chosen. The forecasted scenario that results is called the “most likely future if no action is taken”, which has been mercifully shortened to the without-condition or the without-project condition. In the language of the National Environmental Policy Act (NEPA) this is equivalent to the "no action" scenario. In certain situations it may be more useful to use scenario planning, which relies on multiple without-project conditions. For an introduction to scenario planning see the attached literature review.

The without-condition is likely to be the single most important scenario forecast by planners. It, even more than the base year scenario, is the one scenario that is used in the evaluation of every alternative plan. It is the one common element in all planning evaluation, comparison and selection tasks. An error in the without-condition would be reflected in the evaluation of every plan and it would carry through the decision-making process. Consequently, it is especially important to carefully develop a realistic, credible and science-based without-condition in every planning study.

What Makes a Good Future Condition Scenario?

A good without-project condition (as well as a good with-project condition) is evidence-based. It is conditioned on good science, good data and good models. It uses the best evidence available and ties the analysis directly to this evidence.

A good future condition scenario separates what we know from what we don't know. It clearly identifies the things we do not know for decision makers and anyone with an interest in the study. Furthermore, it identifies those uncertain things that are most critically important to the evaluation of plans and, consequently, are of greatest interest to decision makers. Uncertainties in future conditions should be recognized, identified, described and addressed in an appropriate fashion.

Default assumptions are not used to bridge the gap from what we know to what we do not know. All assumptions used to form a future condition scenario are identified. A good analytical process tests the sensitivity of its results to changes in its assumptions.

All scenarios must reflect reality based on science and field experience. It is important to understand how answers might change if assumptions or inputs change. A good future condition scenario is realistic, honest, unbiased and objective. It tells the truth in a transparent and reproducible way. It is simple, practical, logical, comprehensive, concise, clear, consistent and relevant. The best future condition scenarios are open to evaluation and may include peer review in some situations. They are flexible enough to change if change is warranted.

There is no single right way to forecast a future condition. The idea of forecasting a condition can be confusing because so many of us are inclined to think of forecasting in terms of the techniques that are applied to forecasting individual phenomena, resources, events and variables. Indeed, these techniques are invaluable in the quantitative and qualitative analyses that must be done in order to prepare a condition forecast. Forecasting a condition, however, is the integration of all these disparate parts into a coherent whole that describes the most likely future of the study area under a certain set of assumptions over a common set of criteria.

Each future condition forecast is unique. Although there is no simple set of instructions for how to construct a future condition forecast, there are some recurring elements in most forecasts:

- Identification of the condition to be forecasted
- Assumptions
- Common criteria set
- Supporting analysis
- Integration of parts into a coherent whole condition
- Narrative with supporting documentation

Identify the Condition to Forecast

The first step is to clearly identify the condition that is to be forecasted. An inventory of ***existing conditions*** is a usual baseline (not to be confused with base year) benchmark for most investigations. It is the easiest condition to identify and one of the most important. Every forecast condition, the base year, without-project condition, with-project condition and target condition begins with the existing condition. The existing condition will be the same for all plans.

The ***base year condition*** is a forecast. It is most often an extrapolation from existing conditions. It is a condition that describes what an area will be like when the selected plan first becomes operational. It is not the existing condition; it is not the without-project condition. The base year condition will usually, but not necessarily, be the same for all plans.

The ***without-project condition*** describes what the study area would be like over the entire planning horizon in the planning investigation results in no action. The without-project condition will be the same for all plans.

The ***with-project condition*** describes what the study area would be like over the entire planning horizon if a specific plan is implemented. If a planning study is considering five plans A, B, C, D and E, then there is a with-project condition for Plan A, a different with condition for Plan B, etc. If the with-project conditions do not differ in significant ways the plans are redundant.

The ***target condition*** is usually described in response to a policy or some other expression of public value. In some cases the target may be identified directly (e.g., 500 trees per acre); in other cases it may be identified indirectly (e.g., enough trees to sustain a viable deer population). The latter case would ordinarily involve more analysis.

This manual focuses on the construction of with-project and without-project condition forecasts. There is to be one without-project condition for a planning investigation unless scenario planning is being used, then multiple without-project conditions may be in order. There will be one with-project condition for each alternative plan under consideration.

Assumptions

Assumptions bound and define the future condition forecast. The future is uncertain and, of necessity, so are forecasts of future conditions. Variability in complex natural systems like watersheds can result in a wide range of potential outcomes. Data gaps and limitations to our knowledge result in significant uncertainties. In many instances, assumptions are used to address the analytical problems presented by the existence of variability and uncertainty.

Some assumptions are made explicitly, with the full knowledge and intent of planners. A Risk Register, as found on the Planning Community Toolbox can help to identify understand, organize and identify uncertainties. The Risk Register is designed can help planners identify some of the acceptable risks in their analysis to reduce the overall time and effort of the study. It can also point out risks that can and should be reduced and risks that are unavoidable. For example, in the urban flood studies section of the P&G, analysts are directed to assume that the community is in compliance with National Flood Insurance Program regulations.

Other assumptions are implicit in the policy that guides planning or in the experience and judgment of the planners; oftentimes, the planners do not even realize they are making assumptions. For example, future construction of a controversial highway project could significantly impact a plan. Do you assume the highway will or will not be built? This is an explicit assumption that should be communicated in the without-project condition forecast. On the other hand, when a frequency curve, derived from available data, is used in a study there is an implicit assumption that future stream flows will be statistically like those embodied in the curve. Such an assumption is rarely conveyed to decision makers or stakeholders. A change in a critical assumption causes the entire nature of a future condition forecast to change.

There are some assumptions that need to be recorded in the Risk Register and coordinated with the vertical team because they can affect several different variable or event forecasts. Population growth, for example, affects hydrology and the damage base for a flood damage study. It is important to make explicit assumptions that will be used in common by all study elements when this is the case. Best planning practice would be to specifically identify all explicit assumptions and as many implicit assumptions as possible for each forecast condition.

It is absolutely essential that all members of the planning team use the same future scenarios for their individual responsibilities. This means using the same assumptions, criteria and so on. It is not acceptable for economists to project future land use based on one population forecast while hydrologists forecast future runoff based on a different forecast. The entire planning team must take special care to assure that all members of the team coordinate their efforts and use the same scenario forecasts.

Common Criteria

Forecasts are done so that conditions with and without a plan in the study area can be compared. Common criteria are the things planners want to compare between the two conditions. If reducing flood damages or increasing habitat are planning objectives then planners will need a measure of flood damages with and without the project; likewise, an estimate of habitat units will be needed for both conditions. Planning cannot proceed if different criteria are forecast for the two conditions to be compared. This does not mean that the sets of criteria must be identical for each condition, but they are expected to be extremely similar.

Supporting Analysis

Obtaining estimates of values for the common criteria in the with- and without-project conditions can require a lot of work. The supporting analysis comprises all of the economic, engineering, environmental, social and other work required to forecast future conditions of the common criteria.

The list of common criteria can be misleading, insofar as it can hide the extensive amounts of analyses required to get to a single criterion. Take, for example, expected annual flood damages with and without a plan. This is one common criterion found in every urban flood study. In order to arrive at that criterion, analysts have to inventory and forecast population, land use, structure values, the values of their contents, elevations of real property in the flood plain, delineations of the flood plain, flow-elevation relationships, flow frequency relationships, elevation-damage curves and so on.

It is in this *supporting analysis* element of a condition forecast that traditional forecasting tools and techniques come into play. Hydrologists will use their methods to forecast future flow regimes and their associated frequency of exceedance. Econometrics may be used to forecast structure values. Ecosystem models will be used to forecast the viability of an endangered species in the study area, and so on. This manual does not address the specific details of these analytical tools and techniques as that information and training are available elsewhere.

Integration of Parts into a Coherent Whole Condition

Forecasting a future condition requires a great deal of science, data and sophisticated analysis. Much of that is done by subject matter experts (SMEs). The planning team is responsible for seeing that all of the analysis done in support of the condition forecast as well as the assumptions made get integrated into a coherent description of a holistic future condition for the study area. The individually forecasted items have to make sense together.

The forecasted condition is more than simply a list of all the individual values that have been forecasted —it must not only be reasonable, but also the most likely forecast. The evidence developed in the planning study should be linked to the condition and the condition should be linked to the evidence. A condition should not have conflicting assumptions or analyses. If one supporting analysis suggests low population growth, no other analysis should contradict that. A good condition forecast avoids double counting and mutually exclusive findings.

There are many possible future conditions that can result from the implementation of any one plan. Changing one critical assumption in the definition may cause the condition forecast to change drastically. The variability and uncertainty inherent in future forecasts also suggest the possibility of an infinite number of alternative futures. Although the Corps has begun to use risk analysis in some instances, the planning process still relies on the designation of a single most likely future condition for forecasts of the with- and without-project conditions, in order to proceed.

Care must be taken in dealing with the temporal dimensions of the forecast condition. Suppose the study is completed in year zero, could be operational in year 10, and has a 50-year project life. A without- or a with-project condition forecast is not simply a forecast of conditions in year 60. In a relatively simple planning study it may be reasonable to assume constant conditions throughout the 60-year period, but the reasonableness of such an assumption would have to be established and presented at the outset of the condition forecast.

It is possible, and often rather likely, that some important aspects of the future condition will change and evolve at different rates. As a result, conditions at years 20, 30, 40, 50 and 60 could look quite different from one another. Whether these differences are important enough to affect the selection of a plan must be determined by planners. In some studies it will be sufficient to present a single integrated view of the with- or without-project conditions. This integrated view may include conditions during the last year of the project's life or some other more representative year. In other instances, it will be more instructive to decision makers to summarize the future condition at multiple selected years throughout the planning horizon.

Most importantly, a well-integrated condition forecast supports decision making. It provides the kind of information decision makers will need to make sound and supportable decisions throughout the iterative planning process.

Narrative with Supporting Documentation

A good future condition forecast tells the story of a very specific future well. It covers all the important elements of the story and does so in a clear, concise and transparent narrative fashion. The condition forecast should be summarized in a discrete part of the study documentation. The condition forecast should not be or include a data dump. A strong and effective narrative supplemented with key graphics, tables, maps and displays is sufficient. It will often be desirable to support the narrative with data, details and technical materials. If so, this is best done in appendices. Special care should be given to establishing the rationality of the without-project condition, as it is critical to the evaluation of every planning study.

3.5. Urban Flooding Without-Project Condition

Identify the Condition to Forecast

The without-project condition for an urban flood study describes the nature and extent of the flood problem that will most likely exist from the time of the study through the 50th year of any project's planning horizon if the Corps' planning partnership takes no action to address the flood problem. Bear in mind that the water and related land resource problems may be more complex than an urban flood problem, possibly involving multiple project purposes. If so, the without-project condition will be correspondingly more complex. For simplicity, the urban flooding problem is the focus of this manual and the without-project condition characterizes the flood problem as it is expected to be in the future (absent any action by the Federal government).

Assumptions

National and Corps policy has resulted in the imposition of a number of assumptions that will affect all urban flood damage studies. In summary these are:

(1) **Existing and authorized plans.** Existing flood hazard reduction plans are considered to be in place, with careful consideration given to the actual remaining economic life of existing structures.

(2) **Flood Disaster Protection Act.** The adoption and enforcement of land use regulations pursuant to the Flood Disaster Protection Act of 1973 (Pub. L. 93-234) is assumed.
   a. *Regulation certified or near certification*. If the local land use regulation has been or will be certified, partially waived, or adjusted by the Flood Insurance Administration (FIA) that regulation defines the without-project condition.

b. *Regulation not yet certified.* It is assumed that the local jurisdiction will adopt in the near future land use regulations certifiable to FIA under the without-project condition as a datum and under the with-project condition if a residual hazard will remain.
c. *Application*. It is assumed that flood-proofing costs will be incurred if an activity decides to locate in the floodplain.

(3) **Executive Orders.** Compliance with E.O 11988, *Floodplain Management* and E.O. 11990, *Protection of Wetlands*, is assumed.

(4) **Individual actions.** In addition to the three assumptions previously stated, the analyst shall consider the likelihood that individuals will undertake certain flood hazard reduction measures, such as flood proofing, when the cost of such measures is reasonable compared to the costs of potential flood damages.[5]

Common Criteria Set

Every urban flood damage study will provide a complete description of the flood problem and the expected annual damages caused by that problem. Describing the flood problem includes the following floodplain characteristics from the P&G Procedures:

Physical characteristics of the watershed and floodplain should also be described. This may include topography, slope, soil types and water table.

Existing land use and economic activities should be described. This includes an inventory of the floodplain, a list of existing activity types, the number of acres, and the density, age, and value of structure for each activity-type by flood hazard zone. It may also include an inventory of the jobs, income and tax base

1. **Flooding**. Describe the flood situation, including a designation of high hazard areas. The description should include characteristics of the flooding, such as depths, velocity, duration and debris content; area flooded by floods of selected frequencies, including 100-year frequency; historical floods and, where applicable, larger floods.
2. **Floodway, natural storage**. Describe and delineate those areas which, if urbanized or structurally protected, would affect natural storage, velocity or stage, or would affect flood flows elsewhere.

[5] Source: P&G for Water and Related Land Resources Implementation Studies

3. **Natural and beneficial values, including open space, recreation, wildlife and wetlands**. Many floodplains, particularly those near urban areas, are potential recreation, open space, wetland or wildlife preserves. The potential of the floodplain for these purposes should be recognized and present.
4. **Transportation**. Floodplains near navigable streams have inherent attractiveness for industries that demand water-oriented transportation. Floodplains also serve as sites for railroads, highways, pipelines and related facilities that are not susceptible to serious flood damage but have a tendency to attract industry to the area.
5. **Other attributes**. Other inherent attributes of floodplains may include soil fertility; reliability of water supply; waste disposal; and sand, mineral and gravel deposits.

Physical characteristics of the watershed and floodplain should also be described. This may include topography, slope, soil types and water table.

Existing land use and economic activities should be described. This includes an inventory of the floodplain a list of existing activity types, the number of acres, and the density, age, and value of structure for each activity-type by flood hazard zone. It may also include an inventory of the jobs, income and tax base supported by floodplain activities.

Data collection and analysis sufficient to produce the relationships described in the Expected Annual Damages chapter for the estimation of EAD is the ultimate goal of the analyst. Developing these relationships includes the above evidence and often more.

Forecasts

Developing a forecast of expected annual damages without any Federal action requires a great deal of analysis as suggested above. It also requires the preparation of a land use forecast that is often used for the without- and with-project condition future scenarios. In small local flood protection studies it is often assumed that the floodplain is at or near full development and land use forecasts play a minor role in the economic analyses of these projects. Despite this minor role played in economic analyses, future land use can still have a significant impact on a watershed's hydrology in some instances.

In general, studies that involve large watersheds with local floodplains at or near full development often devote few resources to a land use forecast. In all other studies, however, the land use forecast is a critical foundation element for a without-project condition forecast.

In the past, land use forecasts have been driven by population forecasts. Preparing or obtaining a good population forecast is often a critical task for some urban flood studies. Once the increase in the number of people in the watershed is estimated, these numbers are translated into land requirements. A growth in population will increase the land needed for industrial, commercial, residential and other purposes. These new land requirements are then apportioned to floodplain and non-floodplain locations based on the relative desirability of these different lands.

Land use forecasts can affect expected annual damage estimates in at least two ways. First, they can affect the hydrologic and hydraulic relationships in a floodplain by altering the runoff of a watershed. Second, they can cause an increase (or decrease) in the amount of development and economic activity located in the floodplain. These kinds of changes can affect stage-damage, stage-discharge and discharge-exceedance frequency relationships in the urban flood damage study area.

Supporting Analysis

Once the data for the expected annual damage calculations have been estimated, analysts would use one or more of the available software tools to estimate expected annual damages for as many reaches as warranted by the particulars of the study. Under the with-project condition, the characteristics of the flood problem including the hydrologic and hydraulic information will also be used to design and estimate the costs of structural and nonstructural solutions to the urban flood problem.

Integration of Parts into a Coherent Whole Condition

Forecasting expected annual damages over the next 50 or plus years is a significant challenge in many studies, but it will rarely be the only significant aspect of the without-project condition. More than likely, the expected annual damage calculations will provide only a piece of what is important about the future in a study area. Other important elements will include effects on endangered species and cultural resources; environmental impacts of the flood problem; social impacts such as loss of housing or population base; impacts on jobs, incomes, property values and tax bases and so on. The analyst must integrate the various parts of the analysis into a coherent and consistent whole. A without-project condition is not simply a series of disconnected forecasts of various values. It is an integrated description of all the important resources, variables, criteria and events in a study area for many years into the future.

Narrative with Supporting Documentation

Most reports include a without-project condition description. In best planning practice, this without-project condition description is a coherent and complete narrative that sufficiently describes and characterizes the future condition if no action is taken without bogging the reader down in details. The technical details are provided in technical appendices, separate from the without-project condition narrative.

3.6. Future Conditions and Uncertainty

You have heard it many times now, the future is uncertain. Any single forecast of the future is going to be wrong. Whether the errors are significant or not depends on the quality of the forecast. Forecasting a reasonable without-project condition is usually one of the most important steps in a flood damage reduction study. For example, the without-project condition establishes the expected annual damages, which places an upper limit on flood damage reduction benefits, the principle benefit category in any flood damage reduction study.

The hydro-economic model used by the Corps relies on three specific input functions: the stage-damage, stage-discharge and discharge-exceedance frequency curves. Analysts face uncertainty in preparing each of these inputs because of gaps in their data. Economists, for example, may not have elevation data for each structure in the floodplain. Engineers may have to deal with a hydrologic record limited in its spatial or temporal extent. Recent stream cross-sections may be unavailable. Data gaps are a significant source of uncertainty. In addition, it may be difficult to forecast future runoff patterns and potential flood damages because of uncertainty about future land use in the watershed in general and the floodplain specifically.

It is common practice to use risk analysis to estimate project benefits and to forecast a flood damage reduction project's performance. As practiced by the Corps, this entails a probabilistic analysis of selected variables that have been identified as being critically important in past studies. This approach tends to suffice for flood damage reduction studies because the analytical models are well understood and because the differences in future forecasts of EAD are more a matter of degree than orders of magnitude.

In some cases, however, the most likely future without-project condition is not so easy to forecast. Situations like these are most likely to be encountered in multi-purpose projects that involve hydrologic relationships that are more complex than those of a flood damage reduction study. It tends to be more difficult to forecast the without-project condition for an ecosystem restoration project, for example, than for a flood damage restoration project. What "could be" in the future is sometimes wide open to debate and legitimate differences of opinion can be expected. In situations like these, reliance on a single deterministic without-project condition can be sometimes result in an adversarial process.

In such cases, it may be advisable to make use of scenario planning techniques. In essence, this means forecasting multiple without-project conditions. An unpublished review of the scenario planning literature provides some insight into the history and use of scenario planning. See the attached MS PowerPoint file for a brief overview of scenario planning.

A good planning investigation must address the uncertainty inherent in any forecast of the future. Flood damage reduction studies address the variability and uncertainty in the benefit estimates using risk analysis. Significant uncertainties in the without-project condition may require more drastic approaches such as scenario planning.

Chapter 4: With-Project Condition

4.1 Introduction

The with-project condition scenario is unique and different for each alternative plan. This topic describes the with-project condition for urban flood damage studies. It begins below with the P&G guidance on the with-project condition for flood damage benefit evaluation. This condition is described and illustrated on the next page. Subsequent sections describe how the inputs to the EAD model are modified to reflect the effects of various flood damage reduction measures.

ER 1105-2-100 and the With-Project Condition

The following text defining the with-project condition is taken directly from Corps' guidance in ER 1105-2-100, the Planning Guidance Notebook. Additional policy guidance can be found later in this chapter.

The with-project condition is the most likely condition expected to exist in the future with the implementation of a particular water resources development project. Comparison of conditions with the project to conditions without the project will be performed to identify the beneficial and adverse effects of the proposed plans. The same assumptions that underlie the without-project condition apply to the with-project condition. The assumptions are as follows:

(e) Existing flood hazard reduction plans are considered to be in place, considering the actual remaining economic life of existing structures. If there is a high likelihood of construction of a flood hazard reduction plan authorized for implementation but not yet constructed, the authorized plan is assumed to be in place.

(f) The adoption and enforcement of land use regulations pursuant to the Flood Disaster Protection Act of 1973 is assumed.

(g) For planning purposes, the Corps shall assume that communities in the floodplain belong to the National Flood Insurance Program (NFIP) administered by the Federal Emergency Management Agency (FEMA).

4.2 With-Project Condition

The with-project condition is the scenario that results if the Federal and nonfederal partnership created for the Corps planning investigation implements a plan of action. The with-project condition describes the study area's most likely future if Federal action is taken to solve the problem(s) at hand. This condition must be different from the without-project condition and there must be a unique with-project condition for each alternative plan formulated in a planning investigation. The future of the study area with a plan in place will be different from the future without a plan in place. The with-project condition identifies and highlights those differences in the Evaluation step (Step 4) of the Corps planning process. (For more information about the Corps planning process see the Planning Community Toolbox.) The differences between the without- and with-project conditions are identified by the study team's analysts. A simple flood example was provided in the previous topic.

As noted in the previous topic, the P&G (Chapter 2, paragraph 2.4.3 of the National Economic Development Procedures) has the following to say about the with-project condition.

a. With-project condition. The with-project condition is the most likely condition expected to exist in the future if a specific project is undertaken. There are as many with-project conditions as there are alternative projects.
   1.) In projecting a with-project condition, the analyst must be sensitive to the relationship between land use and the characteristics of the flood hazard for the alternative project being analyzed.
   2.) The same assumptions underlie the with-project and without-project conditions.
   3.) Consideration should be given to both structural and nonstructural alternatives and to alternatives incorporating a mix of structural and nonstructural measures.
   Nonstructural measures include:
      - Reducing susceptibility to flood damage by land use regulations, redevelopment and relocation policies, disaster preparedness, flood proofing, flood forecasting and warning systems, floodplain information, floodplain acquisition and easements; and
      - On-site detention of flood waters by protection of natural storage areas such as wetlands or in manmade areas such as building roofs and parking lots.
   4.) Since project alternatives can differ in their timing as well as in their physical characteristics, the optimal timing of projects and of individual project features should be considered in project formulation.

Consider the following simplified example of plan evaluation. It is based on the EAD calculation presented earlier in the manual. For simplicity this example uses floodwalls of varying heights. Plan A is a wall built to 8 feet above NGVD, Plan B is to 6 feet above NGVD, etc.

	Without Condition	**With Plan A**	**With Plan B**	**With Plan C**	**With Plan D**
Expected annual damages ($000's)	$11,730	$1,542	$2,712	$4,573	$7,297
EAD Reductions	$0	$10,188	$9,017	$7,157	$4,433
Probability of 1 or more floods in 50 years	0.63583	0.07231	0.17043	0.22286	0.36142
Change in habitat units	0	-1000	-750	-500	250

Table 3 : Withouut Project Condition vs With Condition Plans

In Table 3 above: *The without-project condition is the same for each plan. The effects of the different floodwalls on EAD, EAD reduction benefits, the long-term risk of each project and the effect of the plan on habitat units in the project area are shown.*

To calculate the probability of having one or more floods in a 50 year period, first calculate the expected annual exceedance probability (which is the probability of having a flood of a given stage or greater in any given year). According to EM 1110-2-1619, the stage probability function can be used to determine this value. This EM states that analysts should "refer first to the rating function to determine the discharge corresponding to the top-of-levee stage. Given this discharge, the probability of exceedance would be found then by referring to the discharge-probability function: This probability is the desired annual exceedance probability" (3-1). Remember that the rating function is the stage-damage function. If the discharge-probability function and rating function are not known, analysts should use annual event sampling or function sampling. Click here to view an illustration of these steps.

Once the expected annual exceedance probability is known, simply plug the value into the equation below to calculate long-term risk.

$$\boldsymbol{Long\text{–}term\ Risk = 1 - [1 - P]^{n}}$$

$$\text{where } \boldsymbol{P} = \text{expected annual exceedance probability and } \boldsymbol{n} = \text{number of years}$$

The long-term risk of having one or more floods in a 50 year period, for example, would be equal to $\mathbf{1 - [1 - \boldsymbol{P}]^{50}}$.

Notice in the example shown in the table above that if no action is taken, expected annual damages are most likely going to be $11,730,000. If an 8-foot wall is built, damages would most likely fall to $1,542,000. A with-project condition EAD of this amount means the benefits attributable to the wall are most likely about $10,188,000 (since $11,730,000 - $1,542,000 = $10,188,000). Note that these are not risk-based calculations. That topic is taken up in the next topic. For additional discussion, click the following audio files: Table Explanation 1; Table Explanation 2.

Figure 26 below shows the five different damage frequency curves that were integrated to obtain the expected annual damage estimates above. The figure vividly makes the point that the flood damage future is uniquely different with each different project. The labels on the curves represent the floodwall heights.

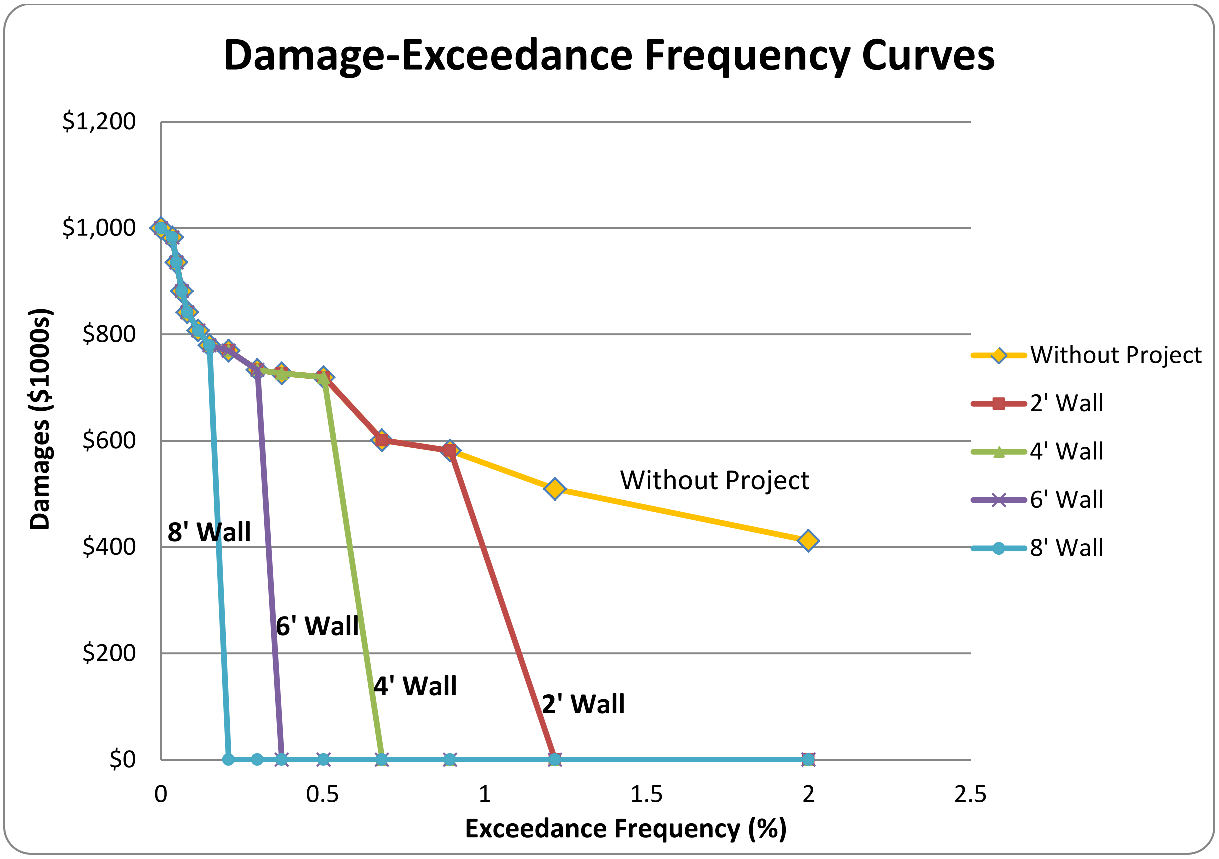


Figure 26: Damage-Exceedance Frequency Curves

The with-project condition is not known with certainty. The study area's future with a project in place may actually be a more certain than the without the project since the nature of the intervention has been determined by the planning partners. Usually the intended results of the planned actions are well known, whereas the results of no action may be less clear. For example, the operation of reservoirs, levees, channels and other flood damage mitigation measures is well known; however the operations of nature are typically more difficult to understand. There may be instances when the future of a particular course of action is uncertain. In this case, planners must identify the *most likely* conditions that will prevail. It is important to remember that the nature of the with-project condition depends on the plan that is being evaluated.

4.3 Flood Damage Reduction Measures

There are six general approaches to reducing the flood damage hazard:

1. Natural Resource Protection
2. Preventive Measures
3. Property Protection
4. Structural Projects
5. Public Information
6. Flood Fighting and Emergency Services Measures

1. **Natural Resource Protection** reduces flood damages by preserving or restoring natural areas or the natural functions of these areas. These measures are usually implemented by park and recreation organizations, conservation agencies or wildlife groups. Examples include:
   - Wetland Protection
   - Best Management Practices
   - Erosion and Sediment Management
   - Riverine Protection Management
2. **Preventive Measures** are intended to keep flood damage problems from developing or getting worse. The use and development of the floodplain and contributing watershed are limited through wise land use. These measures are usually administered by the building, zoning, planning and/or code enforcement officials of the non-federal planning partners. Examples include:
   - Planning and Zoning
   - Open Space Preservation
   - Building Codes and Enforcement
   - Stormwater Management
   - Drainage System Maintenance
3. **Property Protection** focuses on moving people, property and businesses permanently out of unsafe areas. Examples of these measures include:
   - *Property Acquisition*. Public procurement and management of lands that are vulnerable to damage from hazards. Homes are removed from flood-prone areas and the acquired land becomes public property which can only be used as ***open space*** in the future. Open space use is restricted to low impact uses like parks, playing fields, gravel parking lots or agriculture.
   - *Relocation*. Residences and businesses are moved to a safer location. The original site becomes public property while the residence or business remains in private ownership at a new location. The acquired land can be used as open space.

- *Elevation of Structures*. This in-place reduction measure raises the height of the structure's living area above flood levels to reduce property damage and the threat to life. It can also be applied to some businesses.
- *Retrofitting of Homes*. This in-place damage reduction measure raises not the structure but the utilities, services, systems and appliances in some homes above flood levels.
- *Construction Techniques*. To improve structural resistance to water depths or velocities, certain building techniques can be incorporated into new homes or retrofitted into existing structures.
- *Flood Insurance*. Residents and businesses can purchase private insurance policies and participate in the National Flood Insurance Program to protect the property owner from flood damages.

4. **Structural Projects** keep floodwaters away from people, structures and activities in the floodplain. They are usually designed by engineers and managed and maintained by public works staffs or the Corps. They are designed to reduce or redirect the impact of floods. Examples include reservoirs, levees, floodwalls, diversions, channel modifications, and storm sewers (as illustrated below).

Reservoir

Levee

Channel

Storm Sewer

5. **Public Information** programs advise property owners, potential property owners, and visitors of the flood hazards as well as ways to protect people and property from them. They are usually implemented by the nonfederal planning partners. Examples of public information activities include:
   - Flood Maps and Data
   - Library Resources
   - Outreach Projects
   - Technical Assistance
   - Real Estate Disclosure Information
   - Environmental Education Programs
6. **Flood Fighting and Emergency Services Measures** are taken prior to and during a disaster to minimize its impact. These measures are the responsibility of city or county emergency management staff, operators of major and critical facilities, and other local emergency service organizations. They include:
   - Alert Warning Systems
   - Monitoring Systems
   - Emergency Response Planning
   - Evacuation
   - Critical Facilities Protection
   - Preservation of Health and Safety

Some excellent photographic examples and descriptions of many of these measures are provided by Harris County, Texas at Flood Damage Reduction Tools.

4.4 Flood Damage Reduction Examples

Below are examples of many of the flood damage reduction measures planners will use to formulate plans. Additional examples can be found on the Internet.

- Wetland protection. See EPA Wetlands Flood Protection or Clean Water Action Council.
- Erosion and sediment can reduce the carrying capacity of a stream. Stormwater runoff containing sediment can clog existing drainage systems, leading to flooding of streets and structures. High volumes of runoff entering water bodies cause erosion, which can cause greater problems for those downstream of the erosion in the form of mudslides and sediment dumps. See Bioengineering for Hill slope or the Florida Erosion and Sediment Control Inspector's Manual.

- Best management practice. See Agriculture Canada.
- Planning and zoning. See Planning & Zoning Weld County or Sherburne County for examples of local floodplain planning and zoning efforts.
- Open space preservation. See Raritan Watershed or San Antonio.
- Building codes and enforcement. See Greene County, Ohio or Pinellas County, FL.
- Stormwater management. See Greater Vancouver Regional District .
- Drainage system maintenance. The carrying or storage capacity of a drainage system can be greatly diminished by dumping, debris accumulation, soil erosion and sedimentation, and overgrowth of vegetation. Flooding occurs more frequently and reaches higher levels as a result. See Maintenance of the Drainage System, Ontario, .
- Property acquisition. See Charlotte-Mecklenburg, NC, or King County, WA.
- Relocation. See Section 5.1 of the Huntsville, Alabama Flood Mitigation Report.
- Elevation of structures. See Section 5.3 of the Huntsville, Alabama Flood Mitigation Report.
- Retrofitting of homes. See Retrofitting to Protect Your Home From Flooding, Dry Floodproofing, Wet Floodproofing or Panels.
- Construction techniques. See Flood Proofing Measures, Wraps and Temporary Shields manuals are available from FEMA Reading List .
- Flood insurance. See FEMA NFIP, FloodSmart.Gov or Who Needs Flood Insurance ?
- Reservoirs. See TVA Flood Damage Reduction.
- Levees. See Louisiana Levees or download this pdf brochure Levees.
- Floodwalls. See Louisiana Floodwalls for a residential example or download this pdf brochure.
- Floodwalls. Invisible floodplain walls are described by Flood Control America. Flood control gates are also available.
- Diversions. See Santa Clara Valley or Oxbow Bypass.
- Channel modifications. See Structures and Channel Modifications.
- Storm sewers. See Preventing Back Flow or Pumps.
- Flood maps and data. See FEMA Maps.
- Library resources. Go to Ingenta and enter any flood related phrase or term of your choosing.
- Outreach projects. See Public Outreach Strategy.
- Technical assistance. See FEMA, EPA or Snohomish County.
- Real estate disclosure information. See California Department of Real Estate.
- Environmental education programs. See The High Plains.
- Alert warning systems. See Automated Flood Warning System, Fort Collins, or Bangladesh.

- Monitoring systems. See Bloemhof Dam or Yakima Remote Control System.
- Emergency response planning. See Sandbags or Water-Inflated Barriers.
- Evacuation. See Evaluation of Evacuation.
- Critical facilities protection. See Critical Infrastructure Protection.
- Preservation of health and safety. See SBA, FEMA, or Red Cross.

4.5 Expected Annual Damages and the With-Project Condition

A flood damage reduction plan includes one or more of the measures identified in the previous pages. Each one of these measures has some effect on one or more of the three input relationships to the hydro-economic model used to estimate expected annual damages. The effects of damage reduction measures on the various EAD relationships are considered below.

The Stage-Damage Function

A stage-damage function (i.e., depth-damage or damage function) shows the relationship between the depth of water and the amount of damages sustained at that depth (see Figure 27 below). Damages may be separated by contents, structure, business loss, transportation losses and other categories of physical and economic damage. The effectiveness of any plan in reducing these various categories of damages will vary from measure-to-measure and plan-to-plan. It is generally the economist's job to estimate a damage function without and with a plan in place and then to estimate a new damage function for every plan that may alter the damage function.

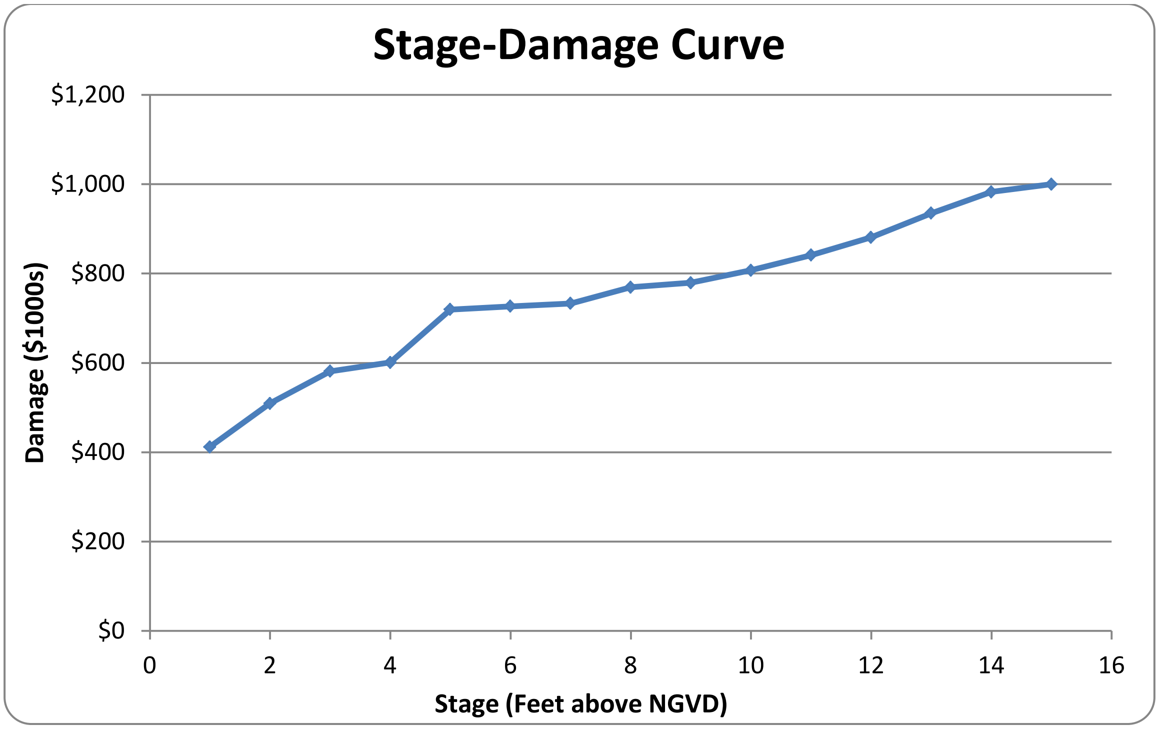


Figure 27: Stage-Damage Curve

To understand the basic nature of the effect a plan could have on a damage function for a reach or project area open the animated MS PowerPoint presentation Stage-Damage and the With-Project Condition. Levees and floodwalls reduce damage by reducing flood stage in the protected area. They do so by blocking overflow from the channel onto the floodplain.

With new or well-maintained Federal project levees, analyses of damages traditionally have been based on the assumption that until the flood stage exceeds the top-of-levee elevation, all damage is eliminated; the levee blocks flow onto the floodplain.

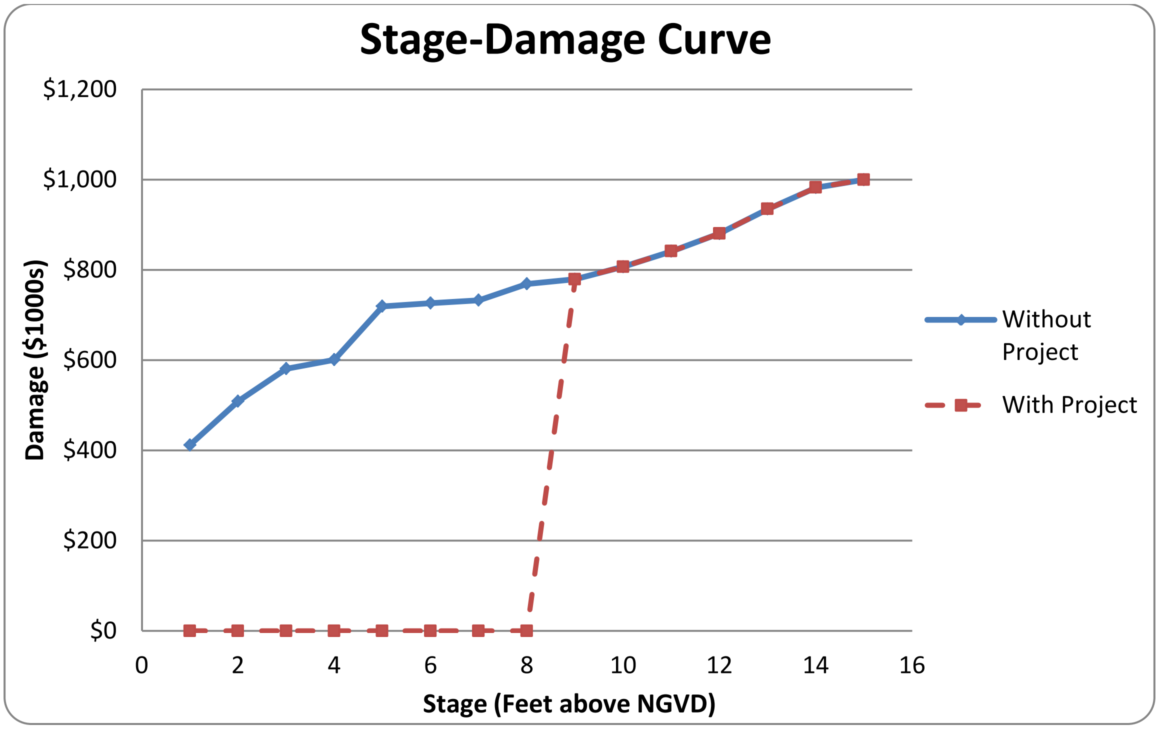


Figure 28: Stage-Damage Curve Showing With and Without Project Conditions

An example of without- and with-project stage-damage functions are shown in Figure 28 above. In the figure above, the solid pink line represents the stage-damage function without the levee, and the dotted blue line represents the function with the levee in place. Damages caused by events from zero to eight feet above NGVD are reduced; Damages caused by events that reach points greater than 8 feet above NGVD are the same as without the new levee.

The STOL ("Stage Top of Levee") is the stage that corresponds to the top of the new levee. With the levee in place, no damage is incurred until the water stage rises to the STOL, 8 NGVD in this example. After this point, damages increase to a value equal to the without-project damage.

The Stage-Discharge Function

A stage-discharge function (i.e., the rating curve) shows the relationship between the amount of water (discharge or flow) and the stage or depth it reaches in the floodplain reach (see Figure 29 below). Some flood damage reduction measures will alter the stage-discharge relationship. A levee or floodwall for example may actually cause a given amount of water to attain a greater depth, causing the rating curve or a part of it to shift upward.

Ordinarily, flood damage reduction measures, like channels and diversions, will cause the rating curve to shift downward. The effectiveness of any plan in reducing damages will vary from measure-to-measure and from plan-to-plan. It is generally the engineer's job to estimate stage-discharge relationships without a plan in place and then to estimate new functions for every plan that may alter the stage-discharge function.

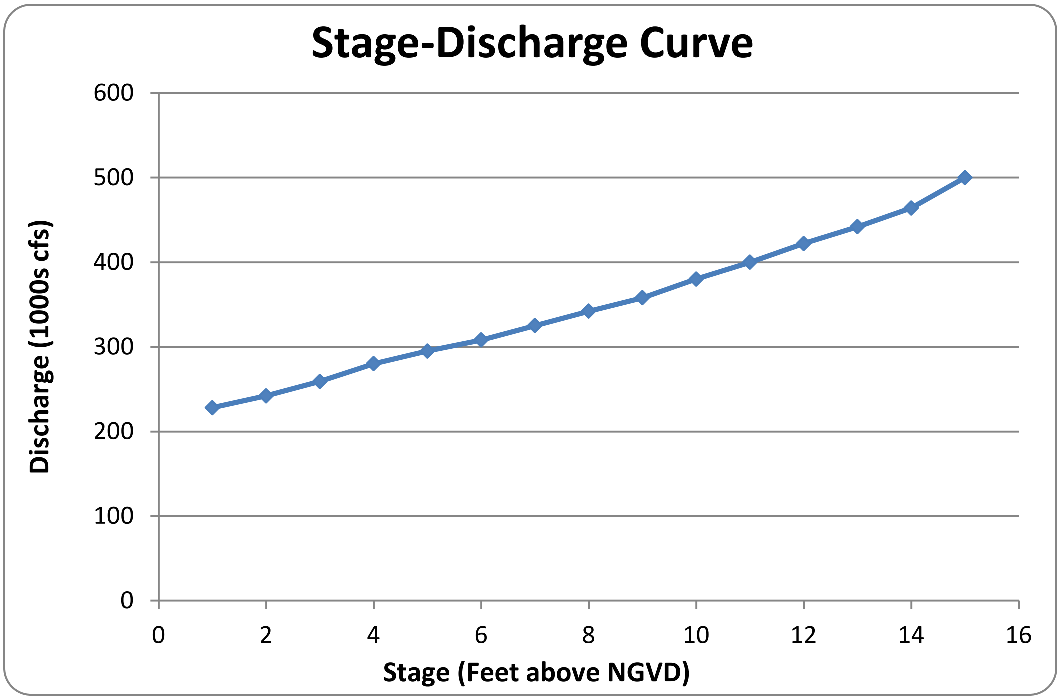


Figure 29: Stage-Discharge Curve

The attached file Stage-Discharge and the With-Project Condition illustrates the basic nature of the effect that a plan could have on the stage-discharge function for a reach or project area. A channel or channel modification reduces the stage for a given discharge. A levee may change the effective channel cross section and alter the stage-discharge relationship. Channel alterations intentionally alter the stage-discharge relationship. An example of a rating curve altered by channel improvements is shown in Figure 30 below.

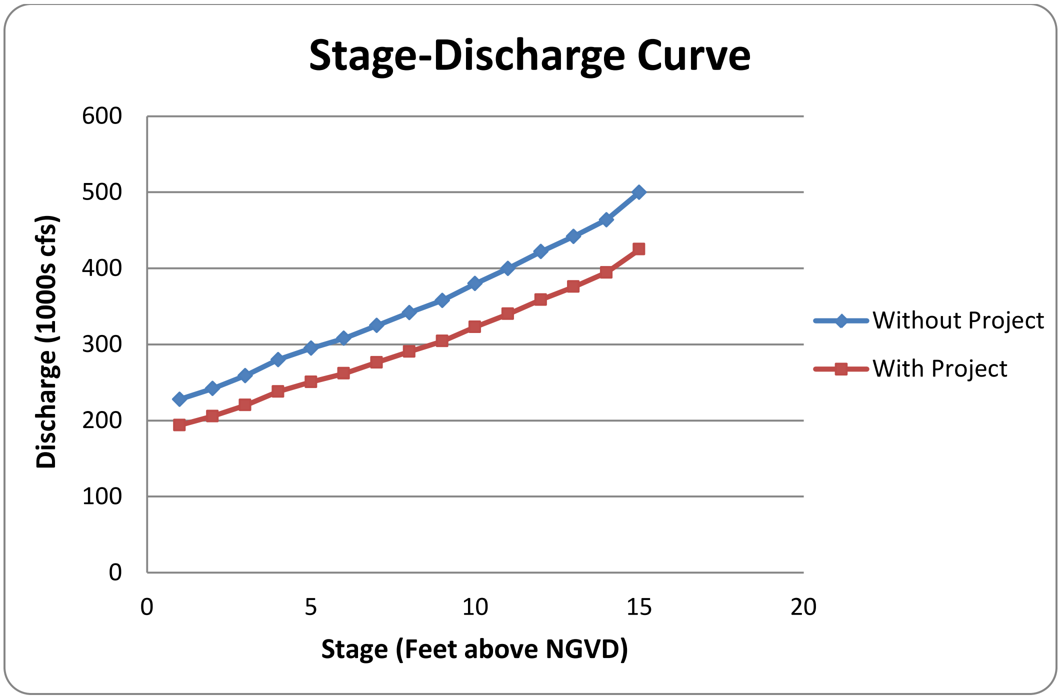


Figure 30: Stage-Discharge Curve Showing With and Without Project Condition

The Discharge-Exceedance Frequency Function

The discharge-exceedance frequency function (i.e., the flow-frequency or frequency curve) shows the relationship between a flow of water (discharge) and the frequency with which a flow of that amount or a greater amount will occur in any given year. Some flood damage measures alter this relationship. Ordinarily, a given flow or discharge will become less frequent, thereby reducing damages. It is generally the engineer's job to estimate discharge-exceedance frequency relationships without a plan in place (see Figure 31 below) and then to estimate new functions for every plan that may alter the discharge-exceedance frequency function.

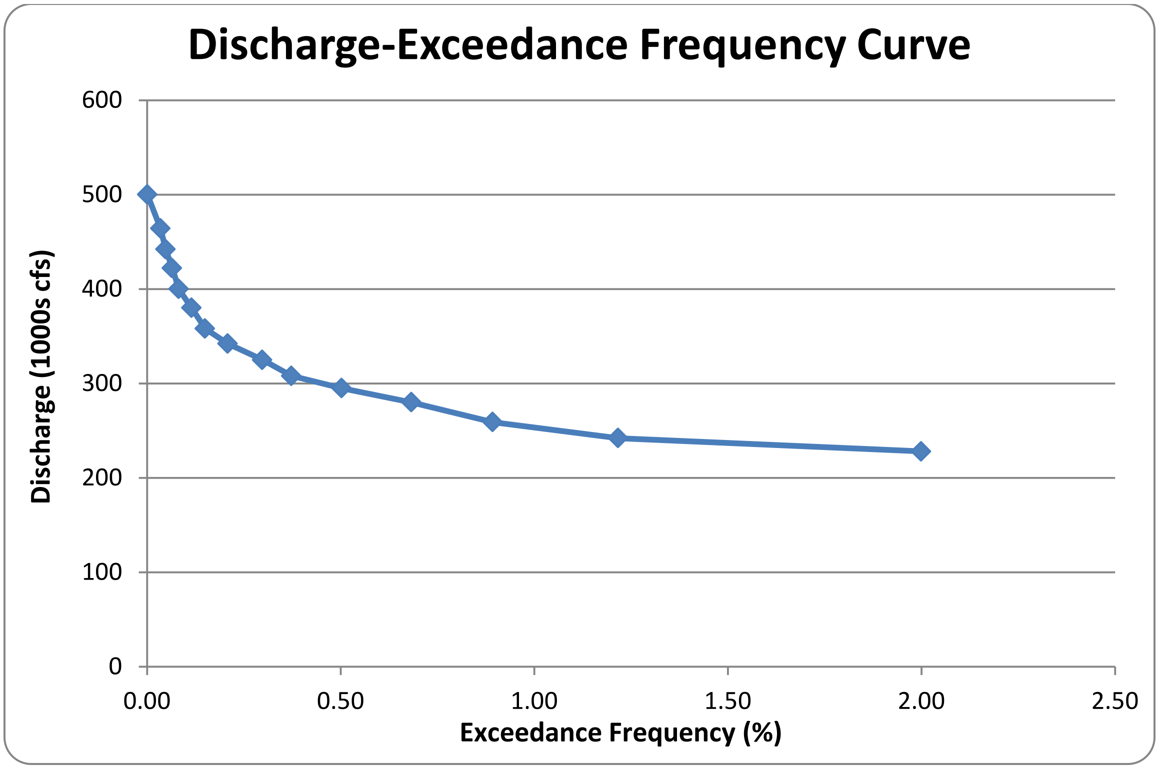


Figure 31: Discharge-Exceedance Frequency Curve

The attached file Discharge-exceedance frequency and the With-Project Condition illustrates the basic nature of the effect a plan could have on the frequency curve for a reach or project area. Engineering Manual(EM) 1110-2-1417 notes that reservoirs, diversions, watershed management, channel alterations and levees or floodwalls may alter the form of the discharge function for the with-project condition. As a diversion alters discharge for individual flood events, it will eventually alter the discharge-exceedance frequency function.

Channel modifications can affect the discharge-exceedance frequency function as well as the rating curve. In many cases, the modifications will increase velocity in the improved section but downstream, where no improvements have been made, there may be a greater discharge and an increase in its frequency.

Furthermore, channel modifications may eliminate some of the natural storage in the channel. This natural storage, like the storage in a reservoir, would reduce flood peaks. In its absence, the downstream peaks may increase, and this too yields an increase in the frequency function quantities. Channel modifications may also alter the discharge-exceedance frequency function if the modifications significantly reduce the timing of the hydrograph through the channel reach. The hydrologic engineer must be aware of the possibility of these incidental impacts, should investigate the change in timing and storage, and must define the modified discharge-exceedance frequency functions if appropriate.

A levee may modify the discharge-exceedance frequency function through its restriction of flow onto the floodplain. This restriction eliminates the natural storage provided by the floodplain, and therefore, may increase the peak discharge downstream of the levee for large events that would flow onto the floodplain without the levee. Further, as the natural channel is narrowed by the levee, the velocity may increase. This, too, may increase the peak discharge for larger events. Reservoirs and detention areas are designed to affect the frequency curve relationship. A conceptual example of the effect of reservoir/detention storage on the discharge-exceedance frequency is shown in Figure 32 below.

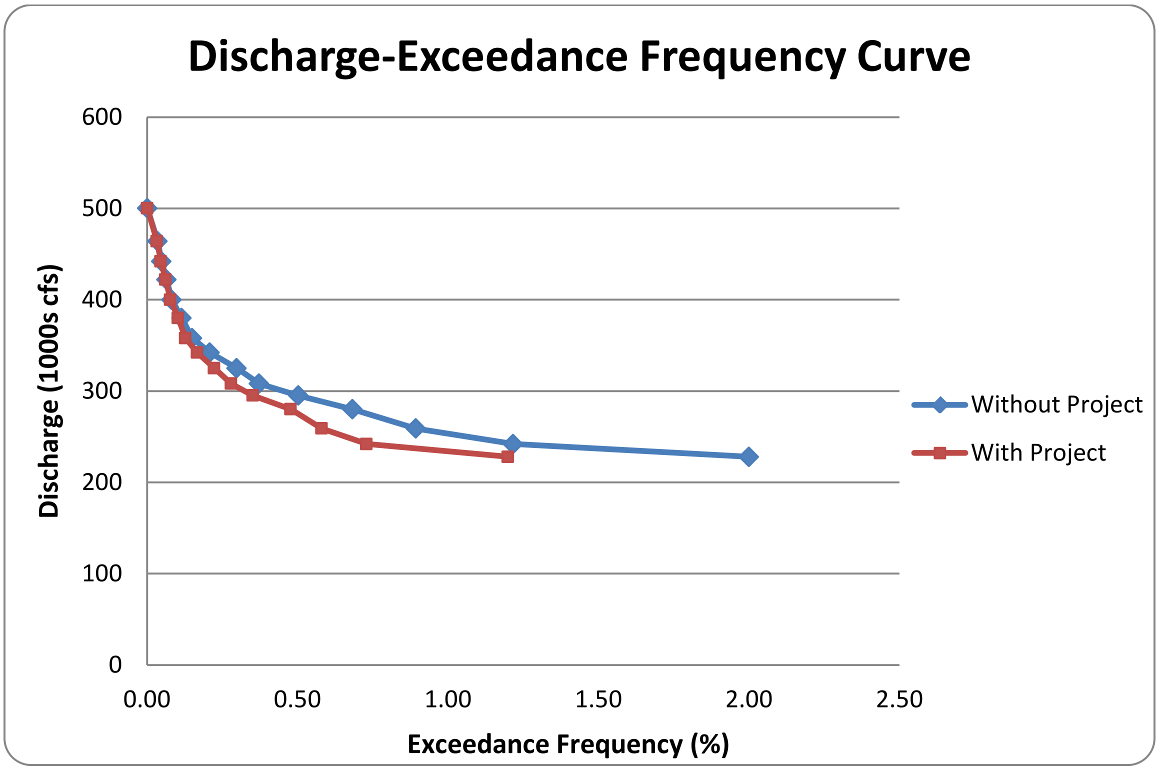


Figure 32: Discharge-Exceedance Frequency Curve Showing With and Without Project Condition

Overall Plan Effect

A plan may consist of many measures. These measures will affect one or more of the three relationships above (namely, the stage-damage, stage-discharge, and discharge-exceedance frequency relationships) and the effect will be different in each reach. When a plan relies on one principal measure the with-project condition analysis of expected annual damages may require changing only one of the three inputs. Plans employing multiple measures may affect all the input relationships in complex ways.

Whether one or more than one of the input relationships changes the damage-exceedance frequency relationship, which is the basis for the expected annual damage estimate, will change as well. This overall change is of most interest to economists. Figure 33 below is reproduced from an earlier page. It shows the without-project condition damage-exceedance frequency along with four different with-project condition damage-exceedance frequency curves. The expected annual damages will differ for each of these conditions. These estimates when compared to the without-project condition produce the estimated flood damage reduction benefits essential to a NED benefit analysis.

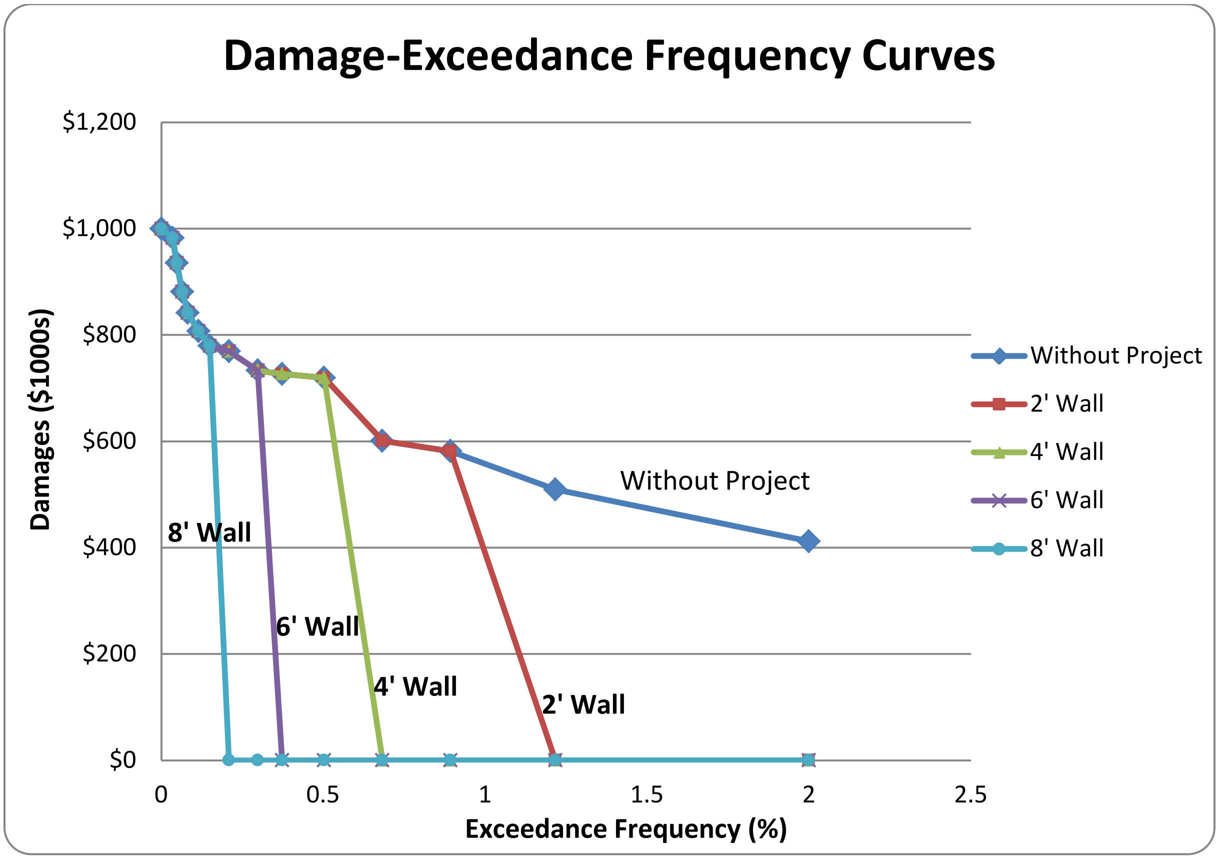


Figure 33: Damage-Exceedance Frequency Curves

The table in Figure 34 below shows the data for two of the curves above, the without-project condition and with the 8-foot wall.

Simple Hydro-Economic Model: Benefits Accruing to Floodwall							
WITHOUT-PROJECT CONDITION							
						ANNUAL DAMAGES	
Discharge	Stage	Exceedance Frequency	Change in Frequency	Damages	Average	At interval	Summation of previous intervals
(000's)	(Feet above NGVD)	(%)	(% interval)	(at stage)	(000's)	(000's)	(000's)
228	1	2.000	--	$411,980	--	--	--
242	2	1.217	0.783	$509,478	$460,729	$3,608	$3,608
259	3	0.893	0.324	$581,244	$545,361	$1,767	$5,374
280	4	0.683	0.210	$601,072	$591,158	$1,241	$6,616
295	5	0.503	0.180	$719,565	$660,319	$1,189	$7,804
308	6	0.373	0.130	$726,761	$723,163	$940	$8,745
325	7	0.298	0.075	$733,043	$729,902	$547	$9,292
342	8	0.209	0.089	$769,356	$751,200	$669	$9,961
358	9	0.150	0.059	$779,384	$774,370	$457	$10,417
380	10	0.115	0.035	$807,236	$793,310	$278	$10,695
400	11	0.082	0.033	$841,379	$824,308	$272	$10,967
422	12	0.065	0.017	$880,982	$861,181	$146	$11,114
442	13	0.048	0.017	$935,127	$908,055	$154	$11,268
464	14	0.035	0.013	$982,638	$958,883	$125	$11,393
	15	0.001	0.034	$1,000,000	$991,319	$337	**$11,730**
WITH-PROJECT CONDITION							
						ANNUAL DAMAGES	
Discharge	Stage	Exceedance Frequency	Change in Frequency	Damages	Average	At interval	Summation of previous intervals
(000's)	(Feet above NGVD)	(%)	(% interval)	(at stage)	(000's)	(000's)	(000's)
228	1	2.000	--	$0	--	--	--
242	2	1.217	0.783	$0	$0	$0	$0
259	3	0.893	0.324	$0	$0	$0	$0
280	4	0.683	0.210	$0	$0	$0	$0
295	5	0.503	0.180	$0	$0	$0	$0
308	6	0.373	0.130	$0	$0	$0	$0
325	7	0.298	0.075	$0	$0	$0	$0
342	8	0.209	0.089	$0	$0	$0	$0
358	9	0.150	0.059	$779,384	$389,692	$230	$230
380	10	0.115	0.035	$807,236	$793,310	$278	$508
400	11	0.082	0.033	$841,379	$824,308	$272	$780
422	12	0.065	0.017	$880,982	$861,181	$146	$926
442	13	0.048	0.017	$935,127	$908,055	$154	$1,080
464	14	0.035	0.013	$982,638	$958,883	$125	$1,205
	15	0.001	0.034	$1,000,000	$991,319	$337	**$1,542**

Figure 34: Simple Hydro-Economic Model: Benefits Accruing to Floodwall

This table shows how a floodwall that prevents flooding up to a stage of 8 NGVD affects the expected annual damages. The without-project condition EAD is $11.7 million and the with-project condition EAD is $1.5 million. The difference, $10.2 million, is the inundation reduction benefit directly attributable to the floodwall.

For a brief discussion of how the with-project condition calculation varies from the without-project condition calculation listen to EAD With-Project Condition.

Uncertainty considered

Does the model presented in this section deal with uncertainty? Yes, in a constrained manner. Through the use of discharge and exceedance probabilities, a degree of uncertainty is incorporated into the analyses. However, the other key relationships (stage-discharge, stage-damage) in the previously discussed hydro-economic model are deterministic since there is no uncertainty consideration in the relationships. Future sections of this manual will consider uncertainty more comprehensively in order to more closely reflect reality.

Chapter 5: Uncertainty

5.1 Introduction

The nature of the world we live in is complex and constantly changing. Because of this, uncertainty is a significant part of nearly every aspect of our lives. Faced with this reality, planners need to devise simple and effective strategies that will enable them to cope and thrive in an uncertain world. A major issue that planners face is the misalignment between the uncertain, malleable context in which they operate and the more deterministic approaches of traditional planning in the past. Current good planning practice by the Corps includes the use of a most likely future without-project condition and a most likely future with-project condition. These are treated largely as deterministic forecasts of the future. Within these scenarios analysts may explore risk analysis of selected events or impacts. A comprehensive risk analytic approach is not yet in general use. Efforts to address the widespread uncertainty in the Corps' planning environment tend to be more ad hoc than institutional or systematic. Despite this, it is fair to say that the Corps is actively working towards incorporating risk analysis to a greater extent in its planning practices.

The Corps planning process would be enhanced by a stronger *culture of uncertainty.* Recent experience with planning on the Upper Mississippi River Tributaries has proven this point convincingly. The future is fundamentally unknowable. There must be recognition of the importance of demonstrating the collective will to act responsibly and accountably with regard to our efforts to grapple with this fundamental uncertainty and the inevitable mistakes that will occur despite every best planning effort to account for this uncertainty. In short, we must recognize that, in an uncertain world, we cannot know everything and we will, therefore, make mistakes despite our best efforts to the contrary. Minimizing these mistakes is directly related to incorporating uncertainty in our planning process.

The manner in which uncertainty is to be addressed in urban flood damage studies is most explicitly addressed in ER 1105-2-101: Risk-Based Analysis For Evaluation Of Hydrology/Hydraulics, Geotechnical Stability, and Economics in Flood Damage Reduction Studies (2006) and in EM 1110-2-1619: Engineering and Design - Risk-Based Analysis for Flood Damage Reduction Studies (1996). ETL 1110-2-556: Risk-Based Analysis in Geotechnical Engineering for Support of Planning Studies (1999), though expired, also provides an in-depth technical framework for the topic. The Corps Risk Analysis Gateway serves as a good reference for current risk-related concepts and applications.

The sections that follow present a conceptual approach to addressing uncertainty in flood damage reduction studies consistent with the Corps current planning practices. The specific details of how uncertainty is addressed, including the probability models used, the variables considered, the calculation algorithms, and so on can vary from one analysis to another. After the conceptual presentation of the uncertainty in an EAD calculation, the methods of EM 1110-2-1619 are summarized in the context of an HEC-FDA example. HEC-FDA is the Corps' standard tool for calculating expected annual damages with uncertainty.

5.2 Engineer Regulation (ER) 1105-2-100 Summarized

ER 1105-2-101 became effective 3 January 2006. Its purpose is to provide guidance on the evaluation framework to be used in Corps flood damage reduction studies. The contents of this guidance are summarized below. Direct quotes from the ER are italicized.

> *Risk and uncertainty are intrinsic in water resources planning and design. All measured or estimated values in project planning and design are to various degrees inaccurate. Invariably the true values are different from any single, point values presently used in project formulation, evaluation and design.*
>
> *The Corps develops best estimates of key variables, factors, parameters and data components in the planning and design of flood damage reduction projects. These estimates are considered the "most likely" values. They are frequently based on short periods of record, small sample sizes and measurements subject to error. Prior to risk analysis, sensitivity analysis had been the primary tool for considering uncertainty in project planning and design. Sensitivity analysis, however, frequently presumes that the appropriate range of values is identified and that all values in that range are equally likely. In addition, the results of this*

analysis are typically reported as a single, most likely value that is treated by some as if it were perfectly accurate.

Risk analyses can be advantageously applied to a variety of water resources planning and design problems. The approach captures and quantifies the extent of the risk and uncertainty in the various planning and design components of an investment project. The total effect of uncertainty on the project's design and economic viability can be examined and conscious decisions made reflecting an explicit tradeoff between risks and costs. Risk analysis can be used to compare plans in terms of the variability of their physical performance, economic success and residual risks.

Budget constraints, increased customer cost sharing and public concern for project performance are issues that must be addressed in the assessment of Federal water resources investments. Explicit consideration of risk and uncertainty can help address these issues and improve investment decisions.

The ER provides definitions of basic terminology as follows:

"Risk" is the probability an area will be flooded, resulting in undesirable consequences.

"Uncertainty" is a measure of imprecision of knowledge of parameters and functions used to describe the hydraulic, hydrologic, geotechnical and economic aspects of a project plan.

"Risk Analysis" is an approach to evaluation and decision making that explicitly, and to the extent practical, analytically, incorporates considerations of risk and uncertainty in a flood damage reduction study.

"Annual Exceedance Probability (AEP)" is the probability that flooding will occur in any given year considering the full range of possible annual floods.

"Residual Risk" is the flood risk that remains if a proposed flood damage reduction project is implemented. Residual risk includes the consequence of capacity exceedance as well.

The ER identifies a number of variables that may be considered in a risk analysis. These include:

- Depth-Damage curves
- Structure values
- Content values

- Structure first-floor elevations
- Structure types
- Flood warning times
- Flood evacuation effectiveness
- Seasonality of flooding and cropping practices (may be important in agricultural analysis)
- The principal variables in hydraulic analyses are discharge and stage
    - Record lengths
    - Effectiveness of flood flow regulation measures is not precisely known
    - Parameters used in rainfall runoff computations
    - Precipitation and infiltration
    - Conveyance roughness
    - Cross-section geometry
    - Debris accumulation
    - Ice effects
    - Sediment transport
    - Flow regime
    - Bed form
- The structural performance of an existing levee (in geotechnical and structural analysis)
    - Levee's physical characteristics and construction quality
    - Difficulties related to locating and installing temporary barriers in a timely manner
    - Variations in retention structure flood control operations

The principles policy requirements of this ER are:

- All flood damage reduction studies will adopt risk analysis as described by the ER.
- The ultimate goal is a comprehensive approach in which the values of all key variables, parameters and components of flood damage reduction studies are subject to probabilistic analysis.
- Instead, a full range of floods, including those that would exceed the Standard Project Flood (SPF), is to be used in formulation and evaluation of alternatives.
- The National Economic Development (NED) plan will be the scale of the flood damage reduction alternative that reasonably maximizes expected net benefits (e.g., expected benefits less expected costs).
- The estimate of net NED benefits and benefit/cost ratio will be reported both as a single expected value and on a probabilistic basis for each planning alternative. The probability

that net benefits are positive and that the benefit/cost ratio is at or above 1.0 will be presented for each planning alternative.

- The flood protection performance will be presented.
- The distribution of residual flood damage and other relevant aspects of residual risks shall also be displayed.
- All project increments comprise different risk management alternatives represented by the tradeoffs among engineering performance, economic performance and project costs. It is vital that the local sponsor and residents understand these tradeoffs in order to fully participate in an informed decision-making process.

The ER provides special guidance on how to evaluate levee performance. The major points of this guidance include the following:

- *The use of freeboard or similar buffers to account for hydrologic, hydraulic and geotechnical uncertainties will no longer to be used in levee planning and design.*
- *Certification of levees must follow current guidelines described in the Federal Emergency Management Agency/USACE memorandum on Levee Certification for the National Flood Insurance Program.*
- *Project performance will be described by annual exceedance probability and long-term risk rather than level-of-protection.*
- *Analysis to assure safe, predictable performance of the project will be included. Such analysis will formulate features to manage capacity exceedance at the least damaging or other planned location. For levees and floodwalls, this may include providing superiority at pumping stations and other critical locations. The analysis of these features will consider their contribution to the project's performance and cost.*

The ER also provides an appendix with helpful documentation and display information.

Engineer Manual (EM) 1110-2-1619

For additional guidance, consult EM 1110-2-1619. The single most comprehensive treatment of the Corps' risk-based approach to flood damage reduction studies can be found in the EM 1110-2-1619: Risk-Based Analysis for Flood Damage Reduction Studies. It provides expanded explanation, examples and considerable application of the principles found in the ER.

In addition, the Corps Risk Analysis Gateway presents an approach to risk and uncertainty that has evolved since 2006. This evolution captures academic advances not yet incorporated into Corps guidance.

5.3 Natural Variability and Uncertainty

As mentioned earlier in this chapter, the Corps is currently working towards incorporating uncertainty more fully into our planning process with the intent to more accurately understand and react to our surroundings. In order to do this, it is essential to understand what is meant when we talk about uncertainty.

Current academic literature used by the Corps (see the Corps Risk Analysis Gateway) describes uncertainty as having two components: (1) natural variability (also simply called "variability") and (2) knowledge uncertainty. Variability refers to changes that occur in our world due to the nature of the systems being studied. Variability is intrinsic to the world around us and is extrinsic to us. It cannot be reduced. An example of natural variability is the change in temperature from day to day. Temperatures vary by nature and although we can study factors that are related to changes in temperature (and therefore help us to predict future temperatures), we cannot change the fact that they vary. In this sense, variability is the component of uncertainty that we cannot reduce. The best we can do to cope with natural variability is acknowledge its presence in our world.

The second component of uncertainty, knowledge uncertainty, can be reduced. Knowledge uncertainty refers to facts that are knowable, but are not currently known by the observer. This type of uncertainty is intrinsic to us. Knowledge uncertainty can be reduced by conducting research to find the answer. An example of knowledge uncertainty is past temperatures. We may not know what the average temperature was yesterday, last week, or last year, but we can do research to determine these facts. In this way, knowledge uncertainty can be reduced.

It is important for analysts to understand the difference between variability and uncertainty. Both contribute to the variation in estimates of project outcomes, e.g., EAD estimates, but only uncertainty due to *facts* that are not currently known can be reduced.

For the purposes of this manual, and in an effort to remain consistent with some past literature regarding risk and uncertainty, we will refer to "knowledge uncertainty" simply as "uncertainty."

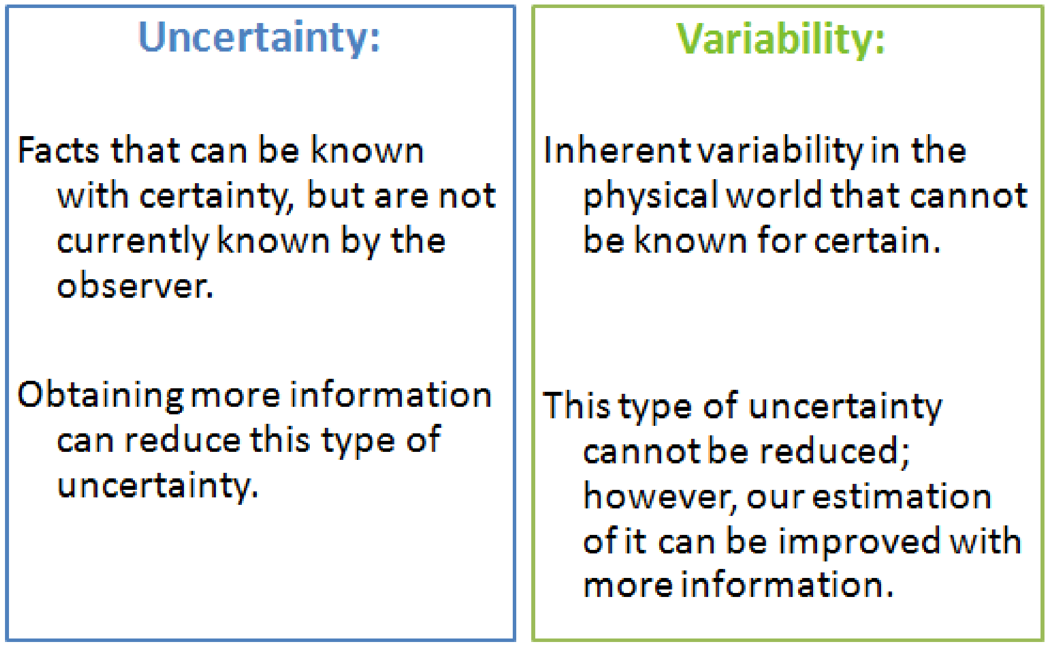


Figure 35: Uncertainty vs Variability

Now consider the two concepts in an example more closely related to urban flood damages: What is the mean peak daily flow of the Susquehanna River at Sunbury, PA? Few, if any, readers will know this value, so it serves as a good example of an uncertain parameter. A parameter is a numerical characteristic of a population that is constant. There is a mean daily peak flow. Regardless of whether we know that value or not, it exists. Likewise, the standard deviation of the flow is a parameter as well. Both of these parameters are unknown to us and therefore, are uncertain.

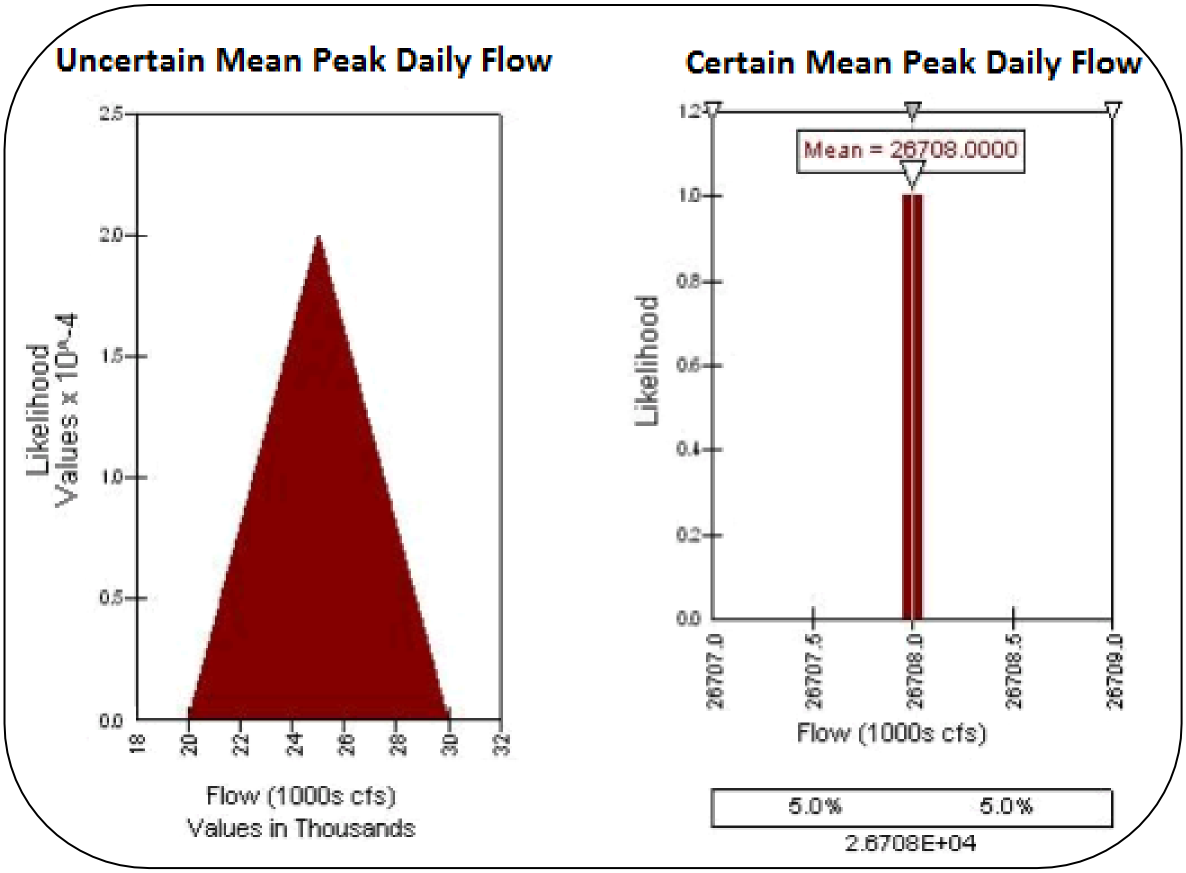


Figure 36: Uncertain vs Certain Mean Peak Daily Flow

On the left in Figure 36 above is a triangular distribution. It is used to represent our uncertainty about the true value of this unknown parameter, the mean peak daily flow. The probability distribution suggests that we believe the value is between 20,000 and 30,000 cfs. This is the segment of the number line represented by the probability distribution. Do we know anything else about this uncertain parameter? Suppose we believe that of all the values between 20,000 and 30,000 cfs the most likely value is 25,000 cfs. These three values and the mathematics of the triangular distribution define the triangular distribution here.

Now suppose this amount of uncertainty is considered unacceptable to planners and so a lengthy and detailed study is commissioned and conducted. After surveying the stream flow for 24,106 days, the study reveals that we can say with a high degree of confidence the mean peak daily stream flow is 26,708 cfs. The figure on the right in the diagram above shows how the distribution has now collapsed to a single deterministic value. This is because our uncertainty has been removed. Years of data have replaced our ignorance with knowledge. But all of these data have done nothing to remove the variability in peak daily flows. They have simply reduced our uncertainty about the true mean value.

Figure 37 below illustrates the natural variability in a hydrologic system that has produced each daily value for the mean peak flow that was studied. The mean value changes from day to day – and this change in value is the variability we are referring to. Note: A copy of these data is attached.

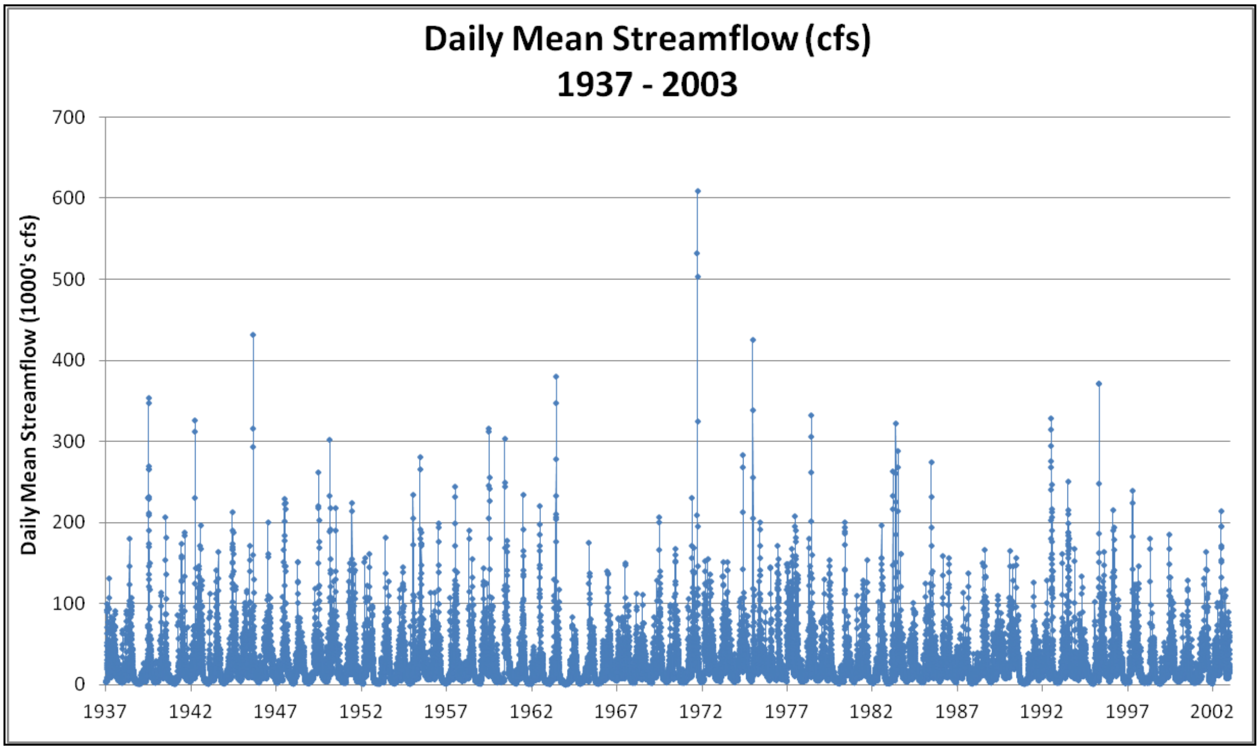


Figure 37: Daily Mean Streamflow (cfs), 1937-2003

The following chart in Figure 38 below summarizes these data by indicating the number of days during the study that each stream flow value was reached. As you can see, the very high stream flow values were rarely reached. Values over 600,000 cfs (though difficult to see due to the scaling of the diagram below) occurred very seldom in comparison to the lower values, for example 1,100 cfs, which occurred nearly 5,900 times.

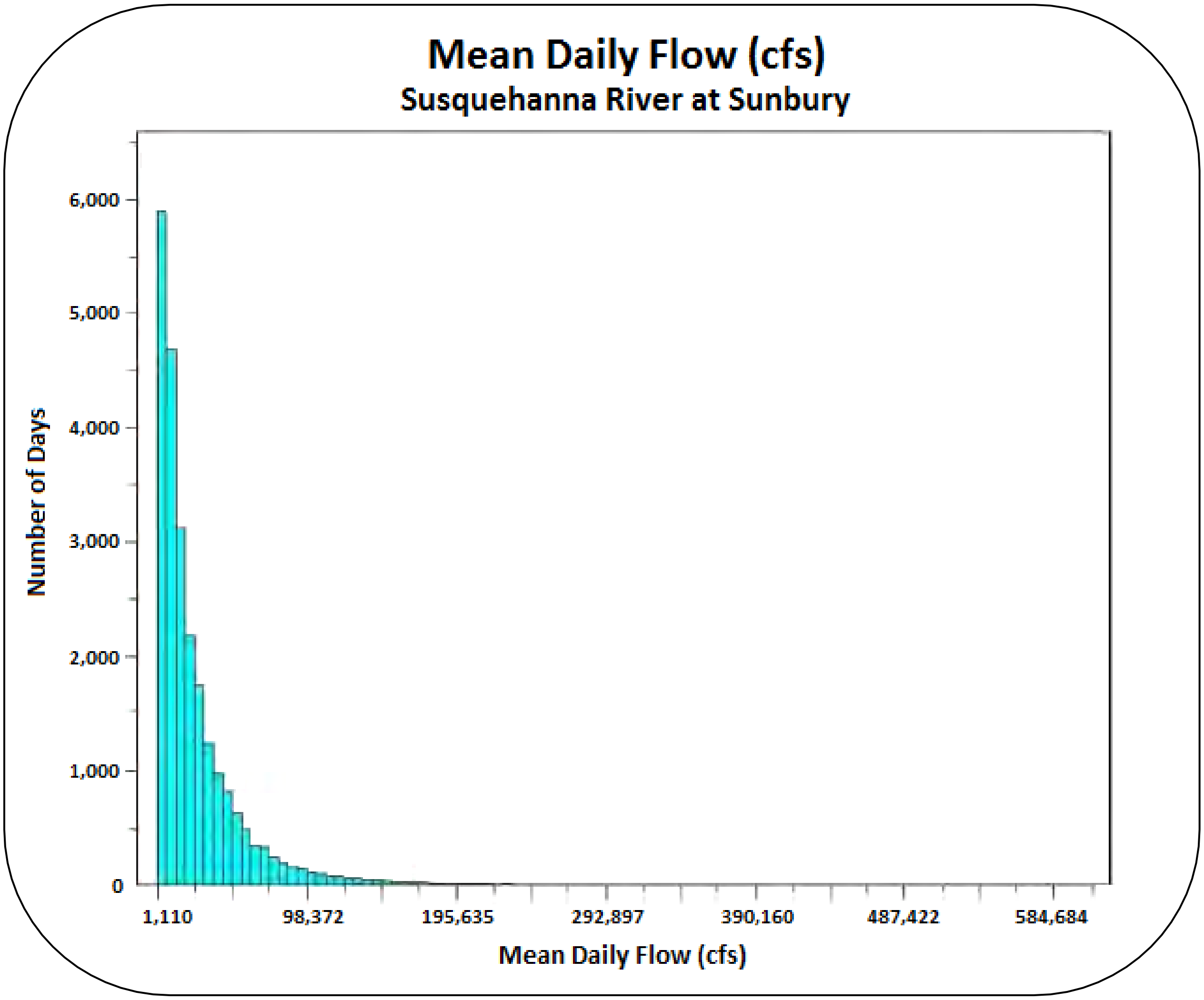


Figure 38 : Mean Daily Flow (cf) - Susquehanna River at Sunbury

Time to review. You are standing on the banks of the Susquehanna River at Sunbury. Do you know what the peak daily flow will be tomorrow? No, of course you do not. But why? Is it because you are uncertain about what the flow will be or is it because the flow is variable? You are certain about the mean flow and its standard deviation. But tomorrow's flow eludes you because of the variability in the hydrologic system that produces flows at Sunbury.

Some problems are problems of variability. We know the parameters but the values of interest still change. Some problems are problems of uncertainty, we do not know the value of the parameters of interest to us. And some problems involve both uncertainty and variability. This would be the case if we had no data about the Susquehanna River. Not only would there be variability in flows but we would be ignorant of the mean flow and its natural variation.

5.4 Thinking about Uncertainty

When we are not sure, we are uncertain. Carefully allowing for the distinction previously made between variability and uncertainty, let us take a look at a systematic way to approach uncertainty.

In a very general way, just what is it that may be uncertain in an urban flood damage study? In the broadest strokes it is:

1. Knowledge
2. Models
3. Quantities

Uncertainty about Knowable Facts

If the reasons behind our uncertainty or lack of information stem from the fact that our theory is not completely developed or our knowledge base may have gaps in it, we consider this to be knowledge uncertainty. Two important distinctions can be made about the state of our knowledge: (1) there are things that are unknown and (2) there are things that are unknowable. When things are unknown to us but are known by others the solution is simple. Learn these things or hire an expert who knows these things. For example, if you do not know the flood history of a community one need only begin to talk to the residents to fill in these knowledge gaps. When the knowledge we seek is unknown to anyone but is knowable, then research can be a practical alternative. This is knowledge that will come in time. The flow regime of a stream may be unknown, but a stream gage and a few years of data collection will help solve this problem.

Some things are unknowable, however, and the knowledge will never come. For example, it would not be wise to spend much time or money trying to ascertain the date on which the Standard Project Flood (SPF) will occur. These things that are not knowable fall under the category of natural variability.

Uncertainty about Models

To sidestep a long and protracted discussion, a model is defined here as simply the way we think about a problem. This encompasses both physical and abstract models. A *physical model* can be iconic, i.e., a scaled-down replica of an object, system or process under study. The Chesapeake Bay model once used by the Baltimore District was an *iconic model*. A physical model could be an *analog model*, which looks like the reality it represents. The best examples of analog models include virtual floodplains and other computer animations. An example is described at Toward Immersive Virtual Environments for GIS-Based Floodplain Modeling and

Visualization. The ship simulators of the Waterways Experiment Station (WES) provide another example of analog models. To view it, click here.

Abstract models are far more common in flood damage studies and they include any real situation described by symbols rather than physical devices. *Descriptive models* simply represent an existing situation. Any mental image translated to a verbal description is a model. So a theory is a simple example of a model. Models need not be mathematical or computer oriented. Many models take the form of simple narratives. In flood damage analysis the majority of abstract models are *mathematical models*. These can be very helpful in solving problems and in revealing the structure of a problem. Examples of mathematical models include logical and quantitative relationships, linear programming, integer programming and non-linear programming models. Equation systems and *simulation models* are also commonly used. Simulation models include physical simulations (like the ship simulators at WES) as well as mathematical simulations, some of which make use of the Monte Carlo process used in the Corps FDA model.

The basic idea behind model uncertainty is simple if we think of a model as a sophisticated representation of how we think about a problem. In this case it simply means, are we thinking about a problem properly? Does our model strike the right balance between being useful and being realistic? The real world can be quite complex and we sometimes simplify it so we can begin to understand it. Early *hydrologic models* often looked at systems as static rather than the dynamic systems they in fact were. There are many software packages, i.e., models, in common usage now and relatively few people who know their inner workings. There are often legitimate concerns about whether or not the results of our model runs are legitimate based on our uncertainty about how well the models that produce them represent reality. The hydro-economic model used to estimate EAD is an example of a mathematical model.

For a vivid example of the challenges set before our models see Hydrologic Systems Modeling used for the Everglades Restoration Study. Model uncertainty is and should be a significant concern for urban flood damage studies. It is important but rarely investigated because it is so difficult to deal with. It is likely that model uncertainty will become a greater concern as more experience is gained in dealing with uncertainty in water resources planning.

Uncertainty about Quantities

Quantity uncertainty is where analysts have had the most experience and success in dealing with uncertainty. There are many different kinds of quantities and the discussion that follows leans heavily on the taxonomy found in Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis. The single most important point to understand from this discussion is that some quantities have a *true* parameter value while others have a *best* or *appropriate* value. There are different sources of uncertainty for each quantity and the best treatment of that uncertainty depends on the type of quantity and the cause of its uncertainty.

Empirical Quantities

Empirical quantities are things people measure or observe. Most of the data used in urban flood damage studies are empirical quantities. Empirical quantities are the only ones with a *true* parameter value. Uncertainty about the true value is possible. Examples include stream flows, structure values, flood depths, content values, first floor elevations, warning times and so on. These all have true mean values, for example. The range of treatments for uncertainty about these kinds of values include using simplifying assumptions, probability distributions, Monte Carlo and other simulation processes, parametric variation, sensitivity analysis and so on.

Defined Constants

Some quantities are constant (and certain) by definition. There is no reason for uncertainty with these kinds of quantities. Examples include the number of square feet in an acre, gallons of water in an acre-foot and the like. There is only one way to address uncertainty about a constant, look up the constant.

Decision Variables

Decision variables are quantities that may be uncertain but they have no true value. Someone simply must decide what the value is going to be. Decision makers exercise direct control over these kinds of values and they can be uncertain about what is the best value. Level of protection is a good example of a decision value. The best, the most appropriate level of protection is not a matter-of-fact. It is a decision someone must make. Cost sharing percentages is another example. The uncertainty in these quantities is best handled with parametric variation, i.e., the systematic changing of a value. For a few words about parametric variation click the audio file.

Value Parameters

Value parameters are quantities that represent aspects of the decision-makers' preferences or values. A value parameter has no true value. Examples include the discount rate or the value of a statistical life; what values will we assign to these variables? Parametric variation is the best way to address uncertainty about what is the best value for these kinds of quantities.

Index Variables

An index variable serves as an indicator of significance. An index variable might identify a location or a point in time or space. There is no true value for these kinds of quantities.

Examples include a reference point such as the flood of record in a stream profile, a rating location, the base year, a particular year in a multiyear model or a geographic grid in a spatial model. Uncertainty about the *best* index value is best treated through parametric variation.

Model Domain Parameters

Model domain parameters are quantities that specify and define the scope of a study or a system modeled. They do not have true values. Examples include the physical extent of the study area, the definition of an industry segment or the planning horizon. Parametric variation is the most useful way to address uncertainty about these quantities.

Outcome Criteria

Outcome criteria result from calculations or other aggregations of other quantities. They measure or rank the desirability of model outcomes. The best examples are net benefits, benefit-cost ratio values, probabilities of various outcomes (e.g., overtopping of protection) and the like. The treatment of these variables is determined by how the uncertain quantities used to derive them are handled.

Sources of Uncertainty in Empirical Quantities

The great bulk of risk analysis and other uncertainty analysis as practiced by the Corps in flood damage reduction focuses on empirical quantities. Continuing with the excellent taxonomy of Morgan et al (1990), the sources of empirical uncertainty are introduced here because the source of uncertainty provides critical direction in the choice of the best way to address the uncertainty.

ER 1105-2-101 identifies a number of empirical quantities including depth-damage curves, structure values, content values, structure first-floor elevations, structure types, flood warning times, flood evacuation effectiveness, seasonality of flooding, cropping practices, discharge and stage. Discharge empirical quantities include flow records, precipitation-runoff computations, cross section geometry, debris accumulation, ice effects, sediment transport, flow regime, and bed form are additional examples of empirical quantities that may be uncertain for a variety of reasons. Here, the different sources of uncertainty in empirical quantities are identified.

Random Error and Statistical Variation

It is rare for planners to have more than sample data. Working with good sample data means the presence of sample error. The mean of a sample, no matter how large the sample, may not equal the true mean of the population because of sample error. Think of sample error as the deviations between sample statistics and population parameters that occur as a result of the chance selection of sample elements that are not exactly representative of the population as a whole. For additional background, see Myth and Reality in Reporting Sampling Error and Statistical Sampling Terms.

In addition, random errors occur in the measurement of variables, especially in the field. First floor elevations are sometimes estimated using maps and hand levels. This is an inexact instrument and elevations may be over or underestimated. A random error suggests that the sum of all errors will tend to equal zero, with overestimates offsetting the underestimates so that, on average, measurements are unbiased. A nonrandom error would result when the measurement errors have a discernible pattern to them. For example, if a hand level is not used properly the investigator may always overestimate the first floor elevation. If a scale is not properly zeroed it might yield measurements that always tend to underestimate weights.

When uncertainty is due to sample error, classical statistical techniques are to be used to address this uncertainty. The best method of addressing random errors will depend on the type of analysis to be done.

Systematic Error and Subjective Judgment

The previous examples of an incorrectly used hand level and a non-zeroed scale can also illustrate systematic error. With this type of error, measurements are systematically off by a certain amount, rendering the true values uncertain. Subjective judgments can also lead to systematic error. Suppose flood damage surveyors are classifying houses as one-story or two-story buildings. How will they handle a split-level home? One may call it a one story with a basement, the other a two-story with no basement. Similarly, subjective judgments of heights may be consistently too high or consistently too low.

The treatments of these kinds of uncertainty are quite different. Checking the accuracy of and calibrating your equipment is one way to reduce this uncertainty. Agree on standards for classifying data before data collection begins. Calibrate the estimates of field personnel if necessary. If one person always overestimates distances and they estimate the size of buildings, it may be necessary to adjust their estimates if the person is systematically off in their estimates.

Linguistic Imprecision

It has been said that half of the world's problems exist because we use different words to mean the same thing; while the other half of the world's problems exist because we use the same words to mean different things. Some uncertainty is the result of the way we use words. What does it mean to measure "ground elevation?" To some this might mean the average height of the ground, to another the lowest elevation, to another the highest elevation. To many people, ground elevation means the highest point to which water can rise around a building without causing any damage to that building. Monte Carlo processes are not necessary to address uncertainty about a quantity that arises from linguistic imprecision. It is important to spend some time clarifying terms.

Variability

Variability has previously been discussed. As noted previously, it is the natural variation that exists in a population. Here we might think of variability as randomness, the effect of chance. It is a fundamental property of the system that produces the population of interest, even if we cannot directly measure it. Variability is not reducible through study or further measurement. It may sometimes be reduced by changing the physical system that produces the population. In the literature, this type of variability is sometimes called *aleatory uncertainty* or *stochastic variability*.

Variability is common in urban flood damage studies. There is variability in flow regimes and in flood plain development. First floor elevations vary and structure values vary. Content values vary. The height a given quantity of water will reach in a building will vary. Variability can be handled in a variety of ways. One common practice is to use probability distributions to model variability as is done with the FDA program.

Randomness and Unpredictability

Some empirical quantities are uncertain because they are unpredictable by our current state of knowledge. Natural disasters like the 2004 tsunami in Southern Asia or Hurricane Katrina in 2005 are good examples of this source of uncertainty. These events are often difficult to address because of their unpredictability.

Disagreement

Some quantities are uncertain because people disagree over their values. Roughness coefficients, Manning's *n* and many other values lend themselves to disagreement. It is relatively common for different experts to arrive at different values. County land use projections may differ from State projections, which may differ from projections prepared by study team members. The partners to a Corps study may well disagree about some values. This type of uncertainty may be treated by a variety of methods. The estimates of different experts may help define a probability distribution. Sensitivity analysis can be done, using first one expert's values, then the other's.

Approximation

The world is complex and rapidly changing. Sometimes our best (and only) option is to approximate how this complex and changing world works. The quantities encountered must sometimes also be approximated. Expected annual damages are a good example of an approximation. Much complex analysis goes into their estimation; many approximate shortcuts are taken along the way to arrive at an estimate of expected annual damages. The manner in which this uncertainty is handled is the subject of the remainder of this chapter. Another good example of the difficulty encountered in dealing with complex and numerous uncertainties can be found by a careful look at the System-Wide Modeling issues faced in the restoration of the Florida Everglades. For some fun examples of water-related approximations click on this link.

5.5 A Few Useful Tools and Techniques

The previous section alluded to the fact that there are a variety of methods for dealing with the uncertainty encountered in the Corps' planning process. This section introduces a few of these techniques.

Acknowledge Uncertainty

The very first step in addressing uncertainty effectively is to acknowledge the existence of uncertainty. A concerted effort to recognize and then to identify the uncertainties present is essential. The most important uncertainties should then be addressed.

This notion may seem a trivially obvious one. It is not. It isn't uncommon for analysts less aware of the significance of uncertainty to deny its existence or importance. When an experienced analyst has more data than ever before it is easy to confuse a plethora of data with certainty. They are not at all the same.

Assumptions

One of the simplest ways to address the data gap problems of uncertainty is to make assumptions. Assumptions can be either explicit or implicit. Explicit assumptions are consciously and purposefully made and, therefore, should be easy to state clearly for others to consider. Implicit assumptions are those assumptions we often make automatically beneath our own awareness. These assumptions are more difficult to state for others. A good review can often surface implicit assumptions.

Research

When an analysis indicates significant data gaps, it is sometimes possible to fill those data gaps by doing research. Research requires time and money, and both of these are usually scarce in a flood damage reduction study. Nonetheless stream flow records can be augmented over time by installing gages, a common form of research in flood investigations. The inventory and forecast part of the Corps' planning process (Step 2) very often entails data gathering or research—the sole purpose of which is to reduce uncertainty about the flood problem.

Sensitivity Analysis

Some outcomes and decisions are sensitive to minor changes in assumptions and input values used for parameter estimates or variables. In such cases, thorough, rational decision making requires an explicit examination of such sensitivities. Often it is not immediately obvious which decisions may be sensitive. Nor is it clear which assumptions and uncertainties may most affect the outputs, conclusions and decisions of an investigation. For this reason, a sensitivity analysis is required whenever there is a substantial amount of uncertainty. The purpose of sensitivity analysis is to systematically find out which decisions are sensitive and to which variables. Sensitivity analysis is a systematic investigation of:

- Model Parameters
- Model Inputs
- Assumptions
- Model Functional Form

These inputs can be varied to examine the effects of changes in these inputs on the outputs of investigations and the outcomes of decisions. Sensitivity analysis is used to increase the decision maker's confidence in the investigation and its results. In the case of flood damage reduction benefits, this type of analysis is used to increase confidence in the reasonableness of the benefits estimate. A good sensitivity analysis provides an understanding of how model output variables respond to changes in the inputs.

Some common sensitivity analysis methodologies include:

- Deterministic One-at-a-Time Analysis of Each Factor
- Deterministic Joint Analysis
- Scenario Analysis
- Subjective Estimates
- Parametric Analysis-Range of Values
- Probabilistic Analysis

Scenario Analysis

Scenario planning has been discussed briefly elsewhere in the manual. When the future is very uncertain it may be advisable to use scenario planning, which relies on the definition of multiple without-project conditions. This is the most extreme use of scenarios to address uncertainty.

In regards to most Corps experience, a scenario analysis analyzes an alternative set of circumstances for a much smaller part of the investigation. For example, estimating EAD assuming an upstream reservoir gets built is one scenario; estimating EAD assuming it does not get built is another. As you may expect, changing key assumptions can lead to different scenarios.

In this context, a scenario is defined by a set of assumptions about model input values. A systematic investigation of different scenarios can identify important variables, i.e., variables to which your output is sensitive. When we use specifically defined scenarios we are using deterministic scenario analysis. Some reasonably common deterministic scenarios that have been used in the planning process include:

- Without-Project Condition
- With-Project Condition
- Optimistic/Best Case
- Pessimistic/Worst Case
- Maximum/Minimum
- Most Likely
- No Action
- Locally-Preferred

Monte Carlo Process

Monte Carlo process is an important tool for our estimation purposes because it provides us with the ability to run many iterations of a model in order to obtain an estimate closer to the true value of a given parameter. The Hydrologic Engineering Center Flood Damage Analysis (HEC-FDA) model will automate this process within the model. The sampling process that has come to be known as the Monte Carlo process was first discovered in the late 19th century. Because it is a computationally intensive technique it was seldom used at the time due to the lack of suitable computing tools. The process gained popularity during the development of the atomic bomb as part of the Manhattan project during World War II.

Although the story of how this happened may be somewhat apocryphal, it has become part of the Monte Carlo folklore and bears repeating. No one had split an atom before and the scientists of the day were quite confident of the theory that suggested the process could be controlled once started. Because the stakes for humanity were rather high, rationality suggested that the conditions under which this fission process would take place be thoroughly investigated. This required the capability to investigate a large number of scenarios. A review of the literature revealed a suitable sampling process, the Monte Carlo process, and some rudimentary computing capability made a systematic simulation of a wide range of conditions possible. The process was applied to a wide range of possible input values until the scientists were convinced the process could indeed be contained as theory predicted.

Since that time the Monte Carlo process has been applied to a wide variety of complex problems involving random behavior. The process itself has two simple steps. First, the procedure generates the value of a random variable from the uniform interval zero to one.

Next, it takes that value and transforms it into a value from a probability distribution that has been defined by the modeler. The Monte Carlo process is not a simulation method per se, but it is a process that has been applied successfully in many simulation models. It is one of the principle processes used in many probabilistic scenario analyses.

Let us suppose we want to know the amount of damage a structure will sustain with 4 feet of water on the first floor. In addition, let us also presume there is uncertainty about the structure's value and the percentage of damage that will result from the flood waters. A very simple model would simply multiply the value of the house by the percent damaged.

The model, then, is given by:

(1) Damage = Value x Percentage

Suppose the house value is $267,500 and the percent damage is 0.522. The damage would be $139,635. But if the structure value is uncertain and the percentage of damage is variable then the actual damage could be more or less than this. The Monte Carlo process provides a way to investigate this range of possible outcomes. For a video demonstration see Part I and then Part II.

To calculate a random value for the value of the structure the Monte Carlo process must execute 2 steps. First, it generates a number between zero and one, then it transforms that number to a useful value for the model.

Step 1: Generate a Random Number in the [0,1] Interval

There are many sophisticated modern methods for generating a random number in the [0,1] interval. For this example the mid-square method attributed to John von Neumann and one of the first methods used, is employed for its ease of understanding and for its historical interest. However, the reader is warned that this method is flawed and is no longer used to estimate random numbers. It is used here because it is simple to explain.

The mid-square method begins with the choice of any numerical value by any method as a seed. Suppose we pick 3,509. This number is squared and the middle four digits are chosen as the "mid-square." Because a 4-digit number was initially chosen, this number is divided by 10^4 to yield a random number r_i. The next value is identified by taking this value and squaring it. The process repeats until as many random values as needed are chosen.

An example follows: Seed =3,509 and $3,509^2$ = 12,313,081; r_1 = 0.3130 $3,130^2$ = 9,796,900; r_2 = 0.9690 $9,690^2$ = 93,896,100; r_3 = 0.8961 and so on. The reader might notice that some seeds yield a remarkably short list of r_i values. For example a seed = 10,000 is of no help. Other seeds begin to cycle a series of numbers with varying lengths of unique values generated. For this reason the method is no longer used.

Step 2: Transform the r_i's Into Useful Values for Your Model

This method is quite simple and nice but it produces values in the [0,1] interval and this problem calls for values in the [$250,000, $285,000] interval. The second step of the Monte Carlo process is to transform the random numbers into numbers that will be useful in your model. A useful number is defined as a value from a specific probability distribution you have defined.

For simplicity one of the simplest probability distributions has been chosen for this example. It has been assumed that the structure value is a continuous value uniformly distributed between 250,000 and 285,000. A uniform distribution is summarized as U = U(a,b) where a is the minimum possible value and b is the maximum possible value the random variable U can attain.

To transform any random variable r_i into a useful value u_i a very simple algebraic function is used:

(2) $u_i = a + (b - a)\, r_i$

which in the present case becomes

(3) $u_i = 250{,}000 + (285{,}000-250{,}000)\, r_i$

Repeated applications of equation (3) yield the following values:

260,955 = 250,000 + (35,000) 0.3130
283,915 = 250,000 + (35,000) 0.9690
281,364 = 250,000 + (35,000) 0.8961

and so on.

A similar, but mathematically more complex, process is going on for the percentage damage variable.

In a Monte Carlo process, deterministic point estimates of values are replaced by probability distributions defined by the modeler. For a sample illustration, click here. An iteration of a model is one recalculation of the model. Each probability distribution in the model is sampled once per iteration. This means a unique random number is generated for each random variable in your model. These values are transformed into useful values for your analysis. The sampled values are then "plugged" back into the equations that define the model, e.g., equation (1) and the model is executed to complete the iteration. A simulation is a technique for calculating a model output value many times with different input values. The purpose of a simulation is to estimate a complete range of all possible scenarios for the variables of interest. A simulation is a set of iterations.

Probabilistic Scenario Analysis

Probabilistic scenario analysis (PSA) combines the use of scenarios and probabilistic methods, like the Monte Carlo process, to characterize the range of potential values for an output and their likelihoods. The EAD model used by the FDA is an example of a PSA.

Scenario analysis often makes use of scenario structuring tools like:

- Event Trees
- Fault Trees
- Decision Trees
- Flow Diagrams
- Process Charts and the Like

The following section shows the EAD model as a tool for probabilistic scenario analysis.

5.6 Understanding Uncertainty in EAD Inputs

It is time to revisit the expected annual damage calculation, this time considering the implications of incorporating uncertainty. The explanation below is given to help analysts understand the concepts that underlie a "risk analysis" of a flood damage reduction study. The exact details of how this is done will vary from one analysis, tool, or technique to the next.

Stage-Damage

Imagine your home with 4 feet of water on your main level. How much flood damage would your home suffer? More importantly, would 4 feet of water always cause the same amount of damage or would the damage vary? Would a Christmas morning flood cause more damage than another flood? Do the contents of your home vary? Is that variation seasonal or random? Would muddy or oily water cause more damage than clear water? It is not difficult to imagine that the amount of damage caused by a given depth of water would vary.

Now let us extrapolate from your home to many floodplain buildings. If damages at your own home could vary, we can expect variations in damages at other buildings as well. A produce wholesaler could have millions of dollars of damages as it is assembling orders for clients and minimal damages if a flood occurred hours after the last order was shipped – this situation considers only the variability in the flood damage that would occur with a fixed depth of water.

Next, let us consider other sources of uncertainty in our damage estimates. We might be working from a sample of structures, introducing uncertainty due to sample error. There could be additional uncertainty introduced because of errors in measurement of first floors, structure values, contents, and so on. Uncertainty could enter the picture for a variety of reasons.

Simple Hydro-Economic Model: Benefits Accruing to Floodwall							
WITHOUT-PROJECT CONDITION							
						ANNUAL DAMAGES	
Discharge	Stage	Exceedance Frequency	Change in Frequency	Damages	Average	At interval	Summation of previous intervals
(000's)	(Feet above NGVD)	(%)	(% interval)	(at stage)	(000's)	(000's)	(000's)
228	1	2.000	-	$411,980	-	-	-
242	2	1.217	0.783	$509,478	$460,729	$3,608	$3,608
259	3	0.893	0.324	$581,244	$545,361	$1,767	$5,374
280	4	0.683	0.210	$601,072	$591,158	$1,241	$6,616
295	5	0.503	0.180	$719,565	$660,319	$1,189	$7,804
308	6	0.373	0.130	$726,761	$723,163	$940	$8,745
325	7	0.298	0.075	$733,043	$729,902	$547	$9,292
342	**8**	**0.209**	**0.089**	**$769,356**	**$751,200**	**$669**	**$9,961**
358	9	0.150	0.059	$779,384	$774,370	$457	$10,417
380	10	0.115	0.035	$807,236	$793,310	$278	$10,695
400	11	0.082	0.033	$841,379	$824,308	$272	$10,967
422	12	0.065	0.017	$880,982	$861,181	$146	$11,114
442	13	0.048	0.017	$935,127	$908,055	$154	$11,268
464	14	0.035	0.013	$982,638	$958,883	$125	$11,393
	15	0.001	0.034	$1,000,000	$991,319	$337	**$11,730**

Figure 39: Simple Hydro-Economic Model: Benefits Accruing to Floodwall

In our initial consideration of the EAD calculation the table in Figure 39 above was used. Look at the flood damage estimate for the stage, 8 NGVD. When water reaches a depth of 8 there will be $769,356,000 in damages in this calculation that treats damage as a deterministic, i.e., a known and certain value. In reality, a water depth of 8 NGVD, could result in a wide variety of damages.

Probability is the language of uncertainty. Probability distributions are often used to represent the state of our knowledge about a variable and/or the extent of the natural variability found in a system (recall the distribution used to display the variability in Susquehanna River flows). The flood damage caused at 8 NGVD is a variable and its distribution is shown below.

To understand what is important for us, consider Figure 40 shown below initially as a picture of the data. First, notice the segment of the number line covered. This shows us where damages are located in number space. The figure also shows the scale of variation in the numbers, roughly from $655 million to $1,100 million.

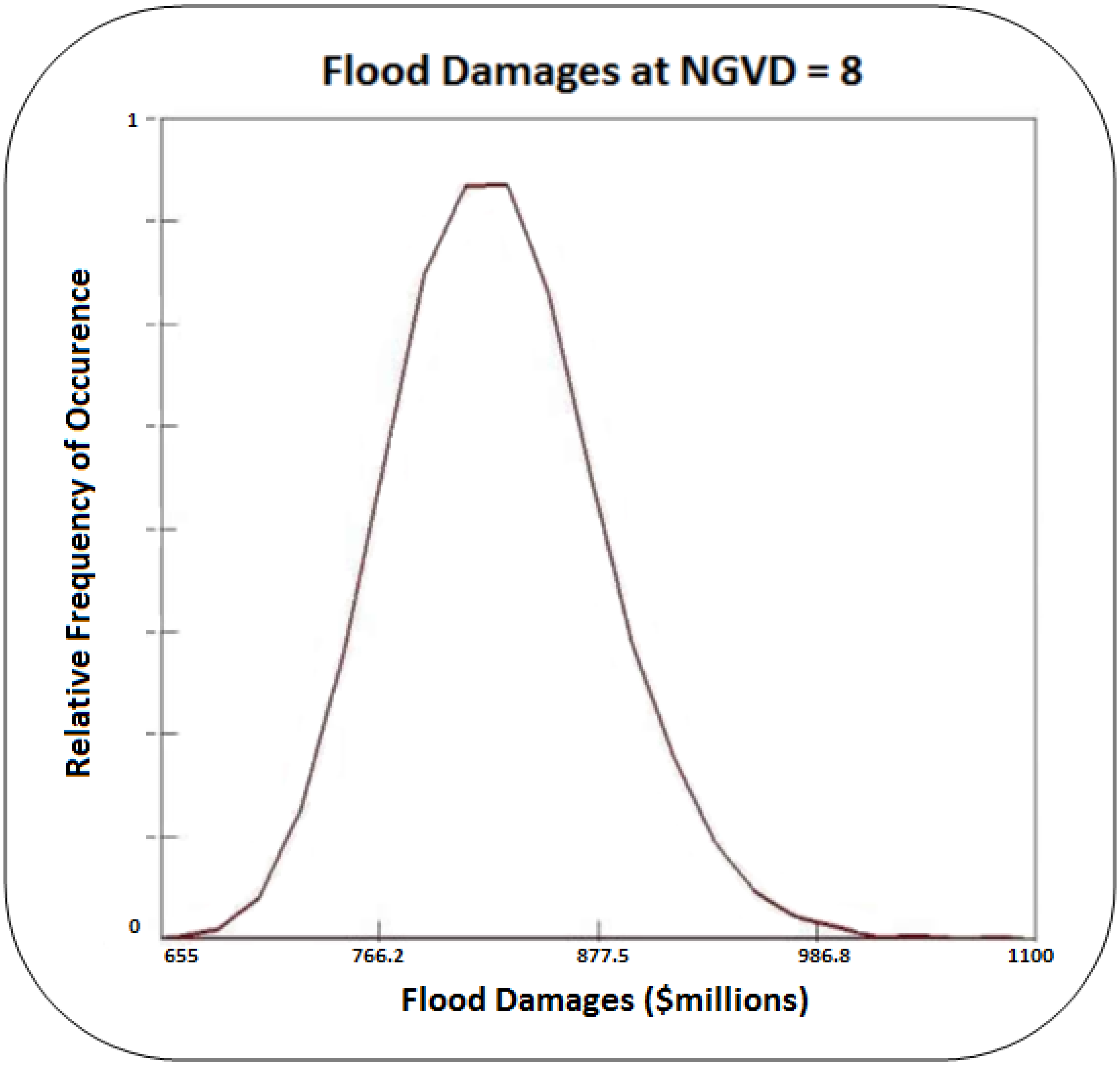


Figure 40: Flood Damages at NGVD = 8

Does the distribution tell us anything else of value about the damages? Indeed it does. The height of the distribution shows us which damage values are most likely to occur. Notice that the extreme values are possible but not terribly likely. In a sense, this figure illustrates the idea that if everything that could go wrong does, damages could be as high as $1 billion. This distribution, in fact, suggests that 95 percent of the time the damages will be between $705 and $937 million. Conversely, there is a 95 percent chance damages from any one flood to 8 NGVD will fall in that interval.

The more important point is that a probability distribution like this is a far more realistic portrayal of the damages that can result from a water depth of 8 NGVD than any single point estimate of damages is. For this reason, the Corps requires a risk analysis of flood damage reduction benefits. This effectively means that each estimate of damages on the stage damage curve should be represented by a probability distribution that captures the uncertainty about the potential flood damages, rather than by a point estimate.

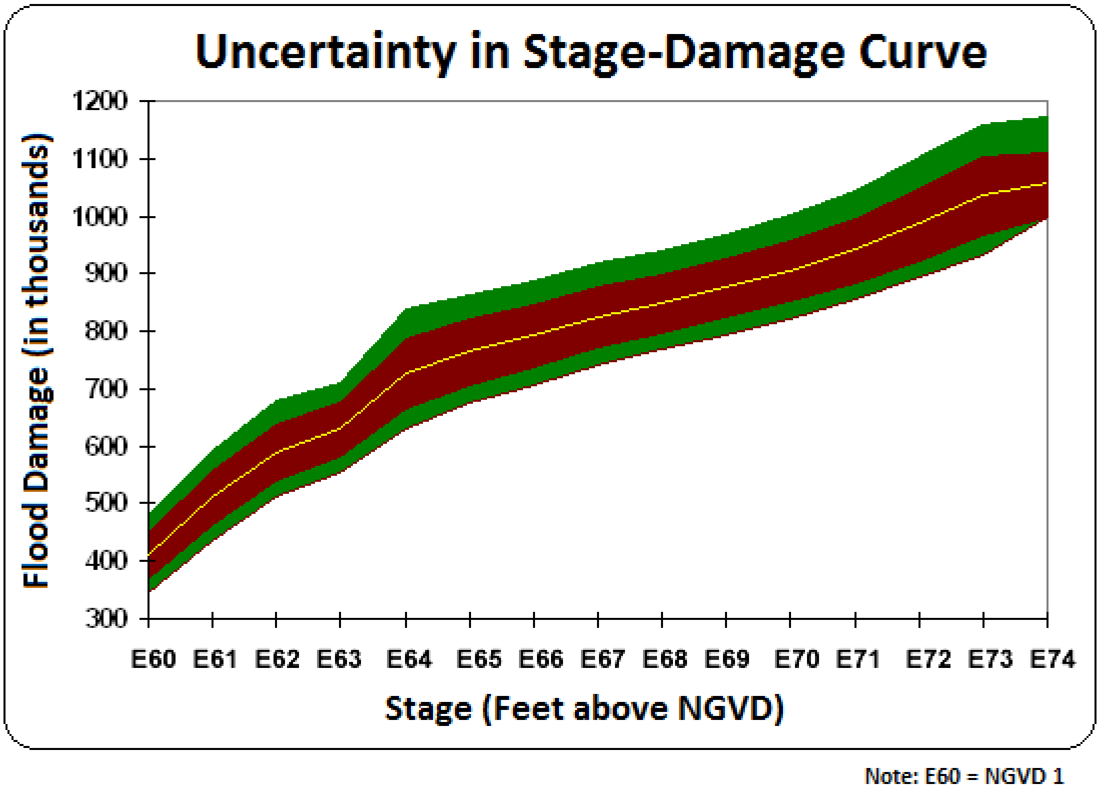


Figure 41: Uncertainty in Stage-Damage Curve

So, in place of each point estimate value in the expected annual damage table above a probability distribution is needed. Figure 41 above illustrates this idea.

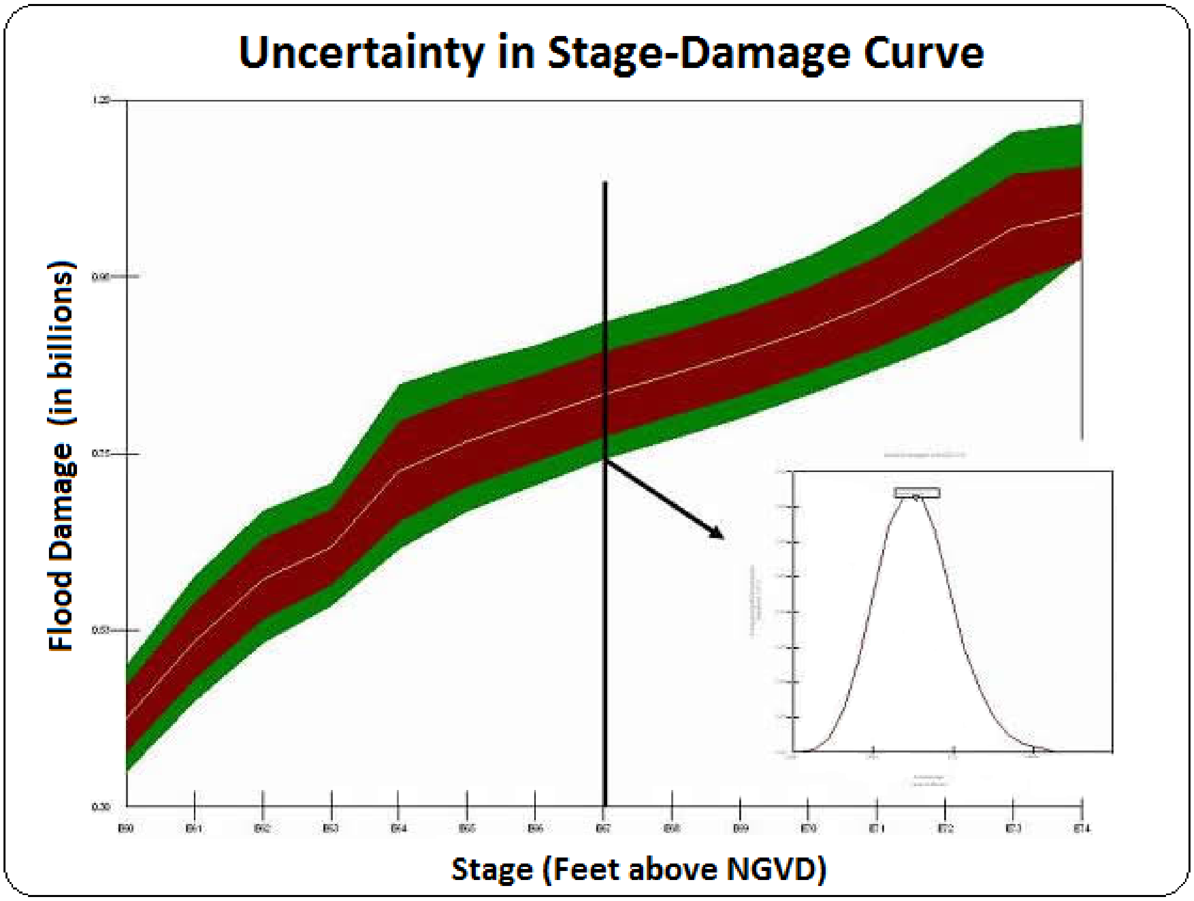
For an explanation of this curve click on the links provided below. Three audio files are provided to offer approximately five minutes of explanation.

Explanation of Curve 1

Explanation of Curve 2

Explanation of Curve 3

The figure above is more accurately a three dimensional curve. Rising out of the page below the brown and green area is a probability distribution. Theoretically, the distribution shown above rises out of the area at the location of the black line. A similar distribution would, conceptually, exist at each point along the horizontal axis. It would also be possible to slice this three dimensional shape horizontally if desired. Such a slice would suggest a given amount of damage can be caused by differing depths of water under the right circumstances.



Note: E60 = NGVD 1

Figure 42: Uncertainty in Stage-Damage Curve

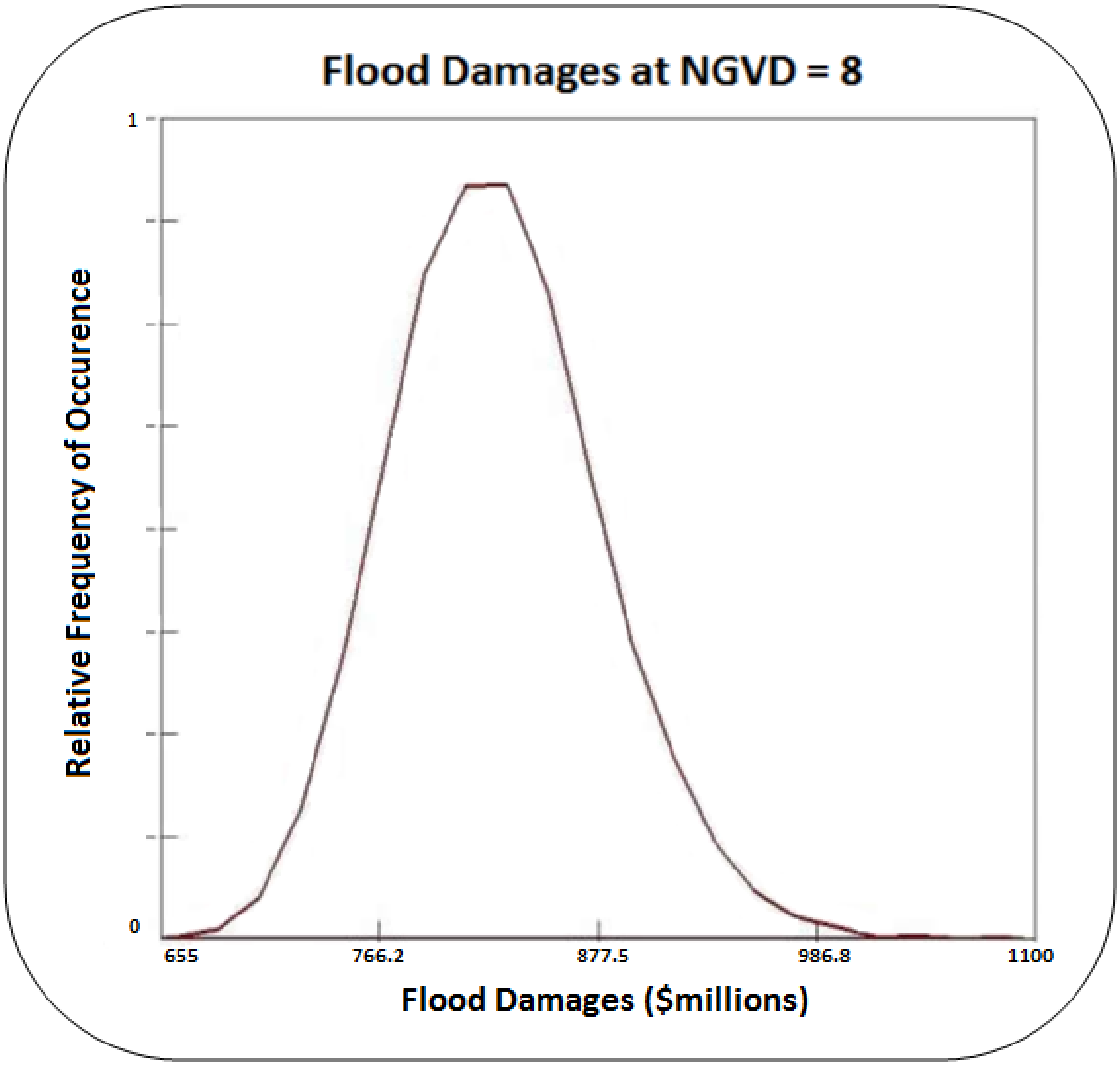


Figure 43: Flood Damages at NGVD=8

Consider the distribution of damages at 8 NGVD we have been discussing. Just what does this distribution represent? In the discussion above it has been noted that there are many potential sources of uncertainty in a stage-damage estimate. Which ones are represented in the analyst's distribution depends on how the distribution was constructed. This distribution represents the likelihood that each given value of flood damages will occur.

The probability distributions used in the Hydrologic Engineering Center's Flood Damage Analysis (HEC-FDA) estimates of damages do not include all sources of uncertainty. The next version of the program will pay more careful attention to explaining the nature of the uncertainties addressed by the model. Although HEC-FDA is a very useful tool, it may not always be ideally suited for the most important sources of uncertainty in a particular investigation. Nonetheless, it is the Corps' standard tool and it is used throughout the Corps. In those instances where the model is not best suited to the uncertainties in an investigation model uncertainty is an additional concern to analysts and decision makers alike.

Stage-Discharge

In a similar fashion, the stage-discharge relationships are subject to uncertainty. Given a specific discharge on a stream, will it always reach the same stage? Would the changes in channel roughness due to vegetation or other seasonal factors affect stage? Might wind or other weather conditions affect stage? These influences, random accumulations of debris, and other factors could result in a system that has some natural variability in the stage that a quantity of water could attain. Once again, this is before beginning to consider other sources of uncertainty including data gaps, measurement errors, changes in channel geometry, model uncertainty and similar considerations.

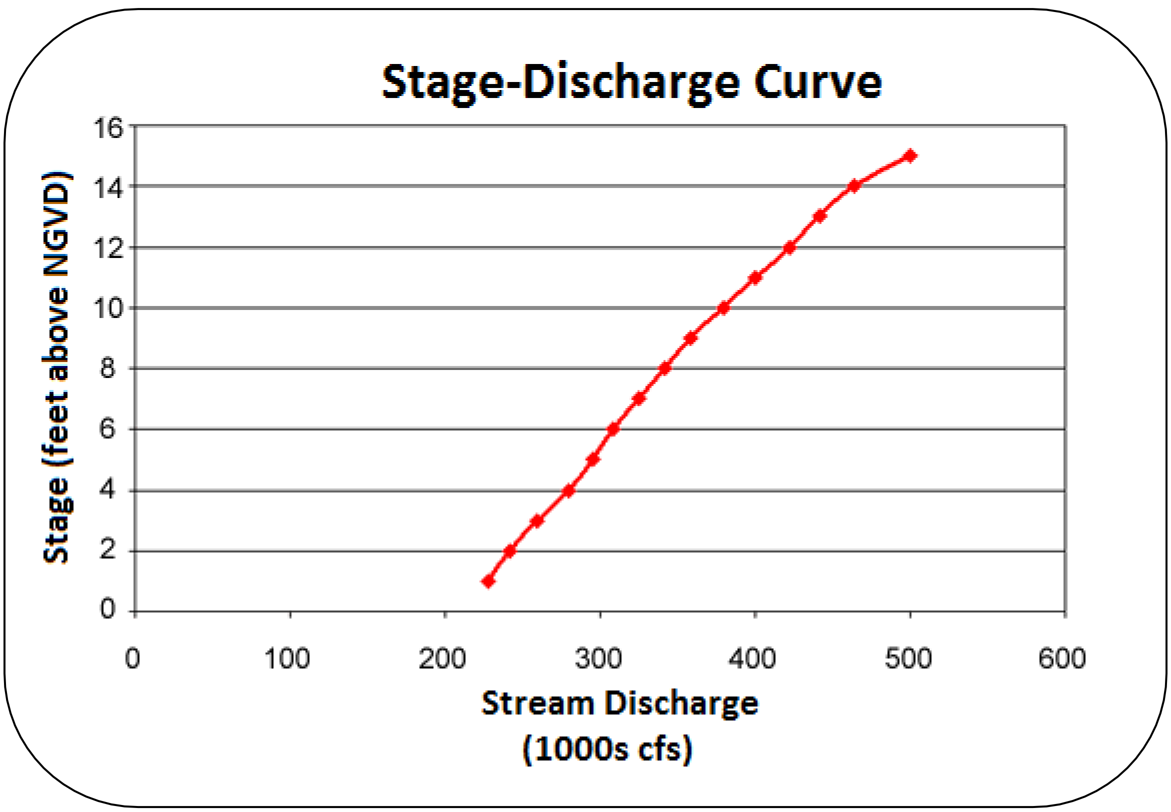


Figure 44: Stage-Discharge Curve

Consider again the stage-discharge relationship from the example we have been using (see Figure 44). Will a discharge of 342,000 cfs always reach 8 NGVD? No. Stated differently, there is some uncertainty about the stage this much water would reach. This flow could actually reach many different heights because of natural variability in the flow regime and because of our ignorance, i.e. the things we do not know about the hydraulic and hydrologic characteristics of this stream.

Figure 45 below illustrates the concept. The distribution is illustrative, rather than factual. Notice that 342,000 cfs may cause the water to reach a variety of stages as a result of the specific sources of uncertainty considered in the analysis.

Imagine such a distribution at each point on the horizontal axis and the three-dimensional figure begins to take shape. It is also possible to consider this relationship from the perspective of stage. If the three dimensional curve is sliced horizontally we would see the uncertainty a bit differently. This would suggest that the same stage can be reached by a range of different flows, given the proper circumstances.

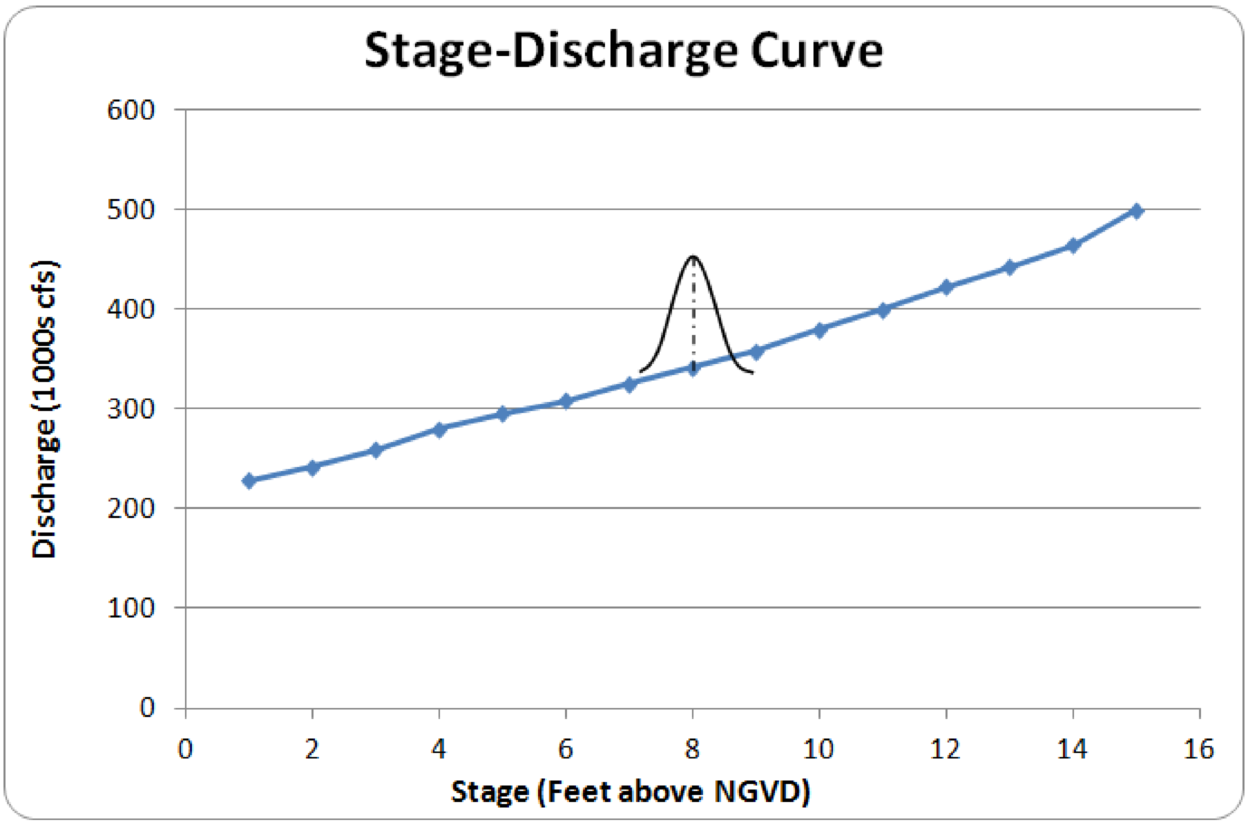


Figure 45: Stage-Discharge Curve

Discharge-Frequency

A discharge-frequency function is critical to the evaluation of flood damage reduction plans. The manner in which the function is defined depends on the nature of the available data. A direct analytical approach is used when a sample (such as stream gage record of maximum annual discharges) is available and it fits a known statistical distribution (such as Log Pearson

Type III). Other approaches are required if recorded data are not available or if the recorded data do not fit a known distribution.

The discharge-frequency relationship is subject to uncertainty. One way to approach the uncertainty would be to ask what the exceedance frequency is of a given flow. Because of data gaps and other non-variability sources of uncertainty, one might describe the exceedance frequency of a specific flow with a probability distribution.

The risk analysis of the Corps (see Chapter 4 of EM 1110-2-1619) has determined the most significant uncertainty associated with the discharge-frequency curve to be uncertainty about the distribution parameters due to sampling error. In other words, the location, scale and shape parameters of different distributions are uncertain due to sample error. These three parameters are estimated using functions that rely on the sample mean, standard deviation and coefficient of skewness. Because these statistics are based on samples, it is possible to calculate confidence intervals for any exceedance probability to express the most significant uncertainty in the Corps' judgment. These statements would come in the forms such as "there is a 90% probability that the parent population mean is between 20,000 cfs and 30,000 cfs." A procedure for calculating these confidence intervals is found in Tables 4.2 and 4.3 of the EM.

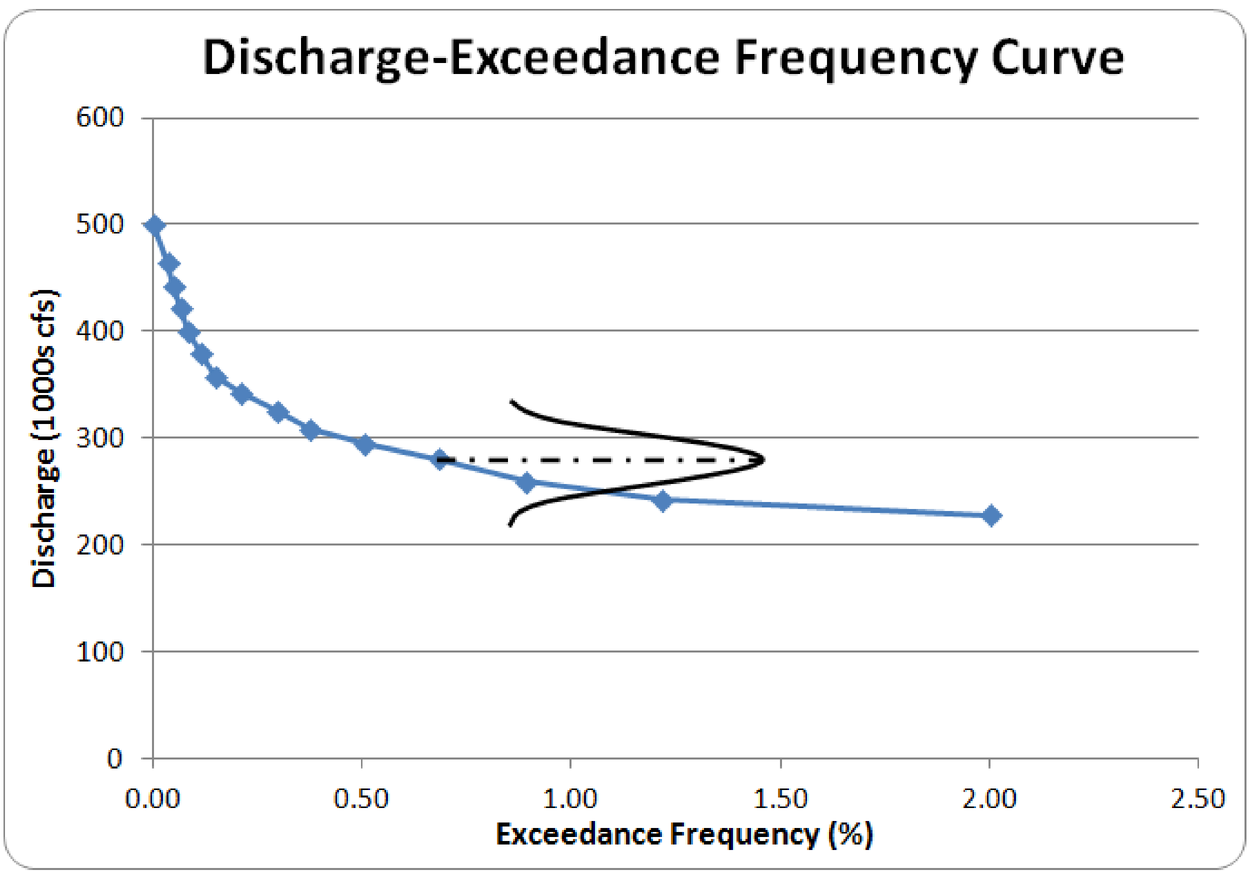


Figure 46: Discharge-Exceedance Frequency Curve

Conceptually, the uncertainty looks similar to that of the other curves (see Figure 46 above). Rather than to focus on population means, the approach is to define an exceedance frequency, such as the 0.005 flow as falling between some range of flows (a conceptual range is shown in the figure), with a specific degree of confidence. Thus, one might say we are 95% certain the 0.005 flow falls between these minimum and maximum values.

5.7 Uncertainty in Calculated Expected Annual Damages

The preceding sections described the uncertainty in EAD calculation inputs. This section provides a simple description of the uncertainty in the calculated EAD. Handling the uncertainty in the inputs is the job of the analyst. Describing the uncertainty in the outputs is also the job of the analyst. Properly considering the uncertainty in the outputs, that is, giving proper weight to what is uncertain, is ultimately the responsibility of the decision maker. In order to enable the decision maker to appropriately consider the uncertainty in the outputs, the analyst must present the results clearly and characterize the uncertainty honestly and objectively.

The bottom line in the estimation of EAD for a flood damage reduction study is that we do not know what the expected annual damages really are. This is because there are so many uncertainties that influence the three key relationships in this model: stage-damage, stage-discharge and discharge-frequency. If the inputs are uncertain, values calculated with them are also uncertain.

Simple Hydro-Economic Model: Benefits Accruing to Floodwall

WITHOUT-PROJECT CONDITION

						ANNUAL DAMAGES	
Discharge	**Stage**	**Exceedance Frequency**	**Change in Frequency**	**Damages**	**Average**	**At interval**	**Summation of previous intervals**
(000's)	(Feet above NGVD)	(%)	(% interval)	(at stage)	(000's)	(000's)	(000's)
228	1	2.000	-	$411,980	-	-	-
242	2	1.217	0.783	$509,478	$460,729	$3,608	$3,608
259	3	0.893	0.324	$581,244	$545,361	$1,767	$5,374
280	4	0.683	0.210	$601,072	$591,158	$1,241	$6,616
295	5	0.503	0.180	$719,565	$660,319	$1,189	$7,804
308	6	0.373	0.130	$726,761	$723,163	$940	$8,745
325	7	0.298	0.075	$733,043	$729,902	$547	$9,292
342	**8**	**0.209**	**0.089**	**$769,356**	**$751,200**	**$669**	**$9,961**
358	9	0.150	0.059	$779,384	$774,370	$457	$10,417
380	10	0.115	0.035	$807,236	$793,310	$278	$10,695
400	11	0.082	0.033	$841,379	$824,308	$272	$10,967
422	12	0.065	0.017	$880,982	$861,181	$146	$11,114
442	13	0.048	0.017	$935,127	$908,055	$154	$11,268
464	14	0.035	0.013	$982,638	$958,883	$125	$11,393
	15	0.001	0.034	$1,000,000	$991,319	$337	**$11,730**

Figure 47: Simple Hydro-Economic Model: Benefits Accruing to Floodwall

Figure 47 above is a familiar table. It shows the calculation of without-project condition expected annual damages. Now, imagine an analysis that addresses the uncertainty in the key hydro-economic relationships here. In other words, instead of the stage-damage curve shown, imagine that there are an infinite number of possible stage-damage curves and likewise stage-discharge and discharge-frequency curves. Each time you hit the recalculate key on the keyboard, a new curve is constructed for each input from the information provided by the analysts.

To illustrate this concept, we simplify the problem and show an example where only the stage-damage curve is uncertain. Allowing all three curves to vary is more realistic but it complicates the example and makes understanding the basic concepts more difficult.

The table below reproduces the EAD calculation with a different damage curve. In this case damages at 8 NGVD are $950 million instead of $769 million. A careful inspection shows an entirely different damage curve. For the calculations below, the stage-discharge and discharge-frequency functions are exactly the same as they are on the table above. In reality, all three relationships will most likely be subject to uncertainties.

	Damage Curve 1			**Damage Curve 2**		
Stage (Feet above NGVD)	**Damages** (at stage)	**At interval** (000's)	**Summation of previous** (000's)	**Damages** (at stage)	**At interval** (000's)	**Summation of previous** (000's)
1	$411,980	-	-	$437,470	-	-
2	$509,478	$3,608	$3,608	$588,955	$4,018	$4,018
3	$581,244	$1,767	$5,374	$594,844	$1,918	$5,936
4	$601,072	$1,241	$6,616	$600,793	$1,255	$1,792
5	$719,565	$1,189	$7,804	$701,213	$1,172	$8,363
6	$726,761	$940	$8,745	$931,287	$1,061	$9,425
7	$733,043	$547	$9,292	$940,600	$702	$10,127
8	**$769,356**	**$669**	**$9,961**	**$950,006**	**$841**	**$10,968**
9	$779,384	$457	$10,417	$959,506	$563	$11,531
10	$807,236	$278	$10,695	$969,101	$338	$11,869
11	$841,379	$272	$10,967	$991,979	$324	$12,192
12	$880,982	$146	$11,114	$1,001,899	$169	$12,362
13	$935,127	$154	$11,268	$1,001,918	$171	$12,533
14	$982,638	$125	$11,393	$1,022,037	$132	$12,665
15	$1,000,000	$337	**$11,730**	$1,032,257	$349	**$13,014**

Figure 48: EAD Calculation Damage Curves

In the tables in Figure 48 above there are two different estimates of without-project condition expected annual damages: $11,730,000 and $13,014,000. The expected annual damage estimate differs because the stage-damage curve differs. The stage-damage curve differs because it is uncertain and we use probabilistic methods, in this case a Monte Carlo process, to represent the uncertainty that affects the stage-damage curve.

Which answer is the best answer? What is the best estimate of expected annual damages?

To answer this question we repeat the calculation of expected annual damages using the Monte Carlo process to obtain many different EAD estimates. Remember that we obtain different estimates with each calculation because the Monte Carlo process randomly chooses the estimates based on its given distribution. Then we can study the EAD estimates to make some informed statements about the true expected annual damages.

Assuming for simplicity the only uncertain function in the model is the stage-damage function, it was allowed to vary using a Monte Carlo process. Five thousand different calculations of the EAD were done and the results are shown below in Figure 49. For an example of this process view the attached video file EAD Monte Carlo.

Output Details Report		
EAD Without-Project Condition		
Minimum	$	10,351
Maximum	$	13,819
Mean	$	12,075
Standard Deviation		469
Variance		219617.6771
Skewness		0.10953585
Kurtosis		3.060486351
Number of Errors		0
Mode	$	11,569
5%	$	11,316
10%	$	11,498
15%	$	11,603
20%	$	11,684
25%	$	11,756
30%	$	11,828
35%	$	11,891
40%	$	11,945
45%	$	11,997
50%	$	12,057
55%	$	12,120
60%	$	12,188
65%	$	12,248
70%	$	12,314
75%	$	12,386
80%	$	12,468
85%	$	12,566
90%	$	12,684
95%	$	12,861

Figure 49: Output Details Report

The lowest of the 5,000 EAD estimates obtained was $10.35 million; the highest estimate was $13.82 million. So, we can be reasonably confident the actual EAD is between these two values. The average of all 5,000 calculations was $12.08 million, and the median was $12.06 million (50th percentile or 50 percent value). A number of other summary statistics are provided as well. It is clear from these data that there is considerable variation in what the EAD value might really be. If the damage curve used in the calculation of the maximum estimate is the true stage-damage curve, then EAD are $13.82 million. They could, however, just as easily be any value in the range obtained by this risk analysis, although some values are clearly more likely than others (as the figures below will show).

Using the deterministic model we began with, we believed the expected annual damages were $11,730,000. This is a very precise statement, but the confidence we can place in a point estimate is very small. There is effectively no chance this is the exact true value of EAD. For an explanation of this click the audio file.

The summary table enables us to make statements that address the consequences of our uncertainty about model inputs (in this example, the stage-damage curve). We also have more confidence in the estimate, although at the cost of some precision. The true value of EAD is believed to be between $10.35 million and $13.82 million. The most likely value (the mean) is $12.08 million. There is more than a 75 percent chance actual EAD are greater than the point estimate of $11.76 million. Based on the analysis, we are 90 percent sure the actual EAD is between $11.32 (5th percentile) and $12.86 million (95th percentile).

The results of the uncertainty analysis are shown below graphically in Figure 50. For a video summary of this characterization of the EAD view the video file. The first of the following graphics is a histogram, and next is a cumulative distribution function (CDF). The histogram provides an effective visual display of the extent and manner in which the EAD values are spread over the number line. The CDF provides the opportunity to locate any value on the horizontal axis and to find its corresponding vertical axis value, which shows the percentile corresponding to any value of interest, for example, the original fixed point value of $11.73 million (about a 23 percent chance of this value or less).

Risk analysis estimates of expected annual damages enable analysts to provide a much more thorough characterization of the true value of expected annual damages in an uncertain world.

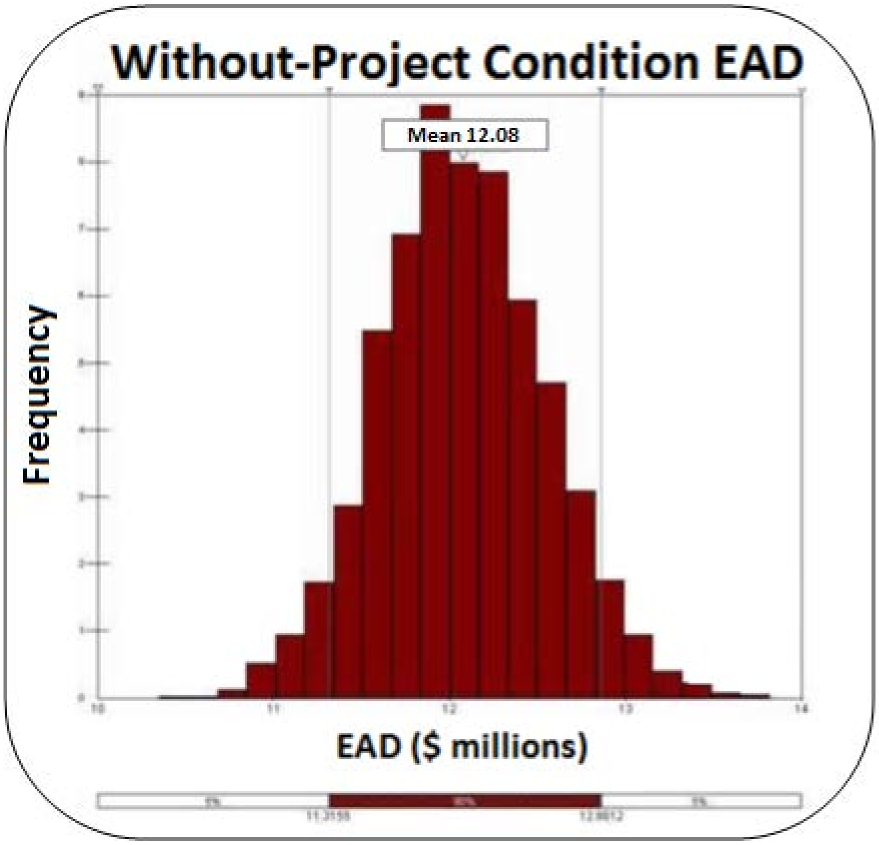


Figure 50: Without-Project Condition EAD

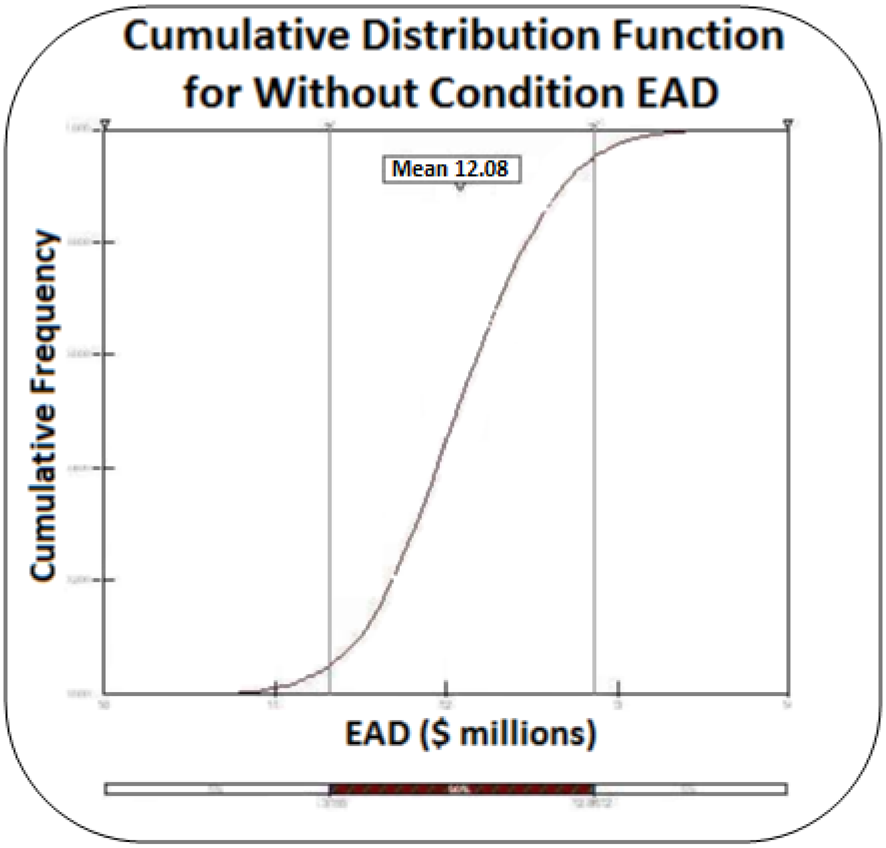


Figure 51: Cumulative Distribution Function for Without Condition EAD

This example addressed uncertainty in the stage-damage function only. In best planning practice, the stage-discharge and discharge-frequency curves would also address the uncertainty in these relationships. This would result in EAD distributions like those in Figure 51 above but the range of values would likely increase to reflect the additional uncertainty.

In addition, this example addresses only the uncertainty in the without-project condition. Consideration of the with-project condition introduces another new risk analysis of the uncertainties associated with the changed hydro-economic system produced by the plan being analyzed.

Finally, the example used throughout this manual was simplified to provide easier access to the concepts underlying urban flood damage reduction studies. Modern computers and the latest generation of software tools make it possible for analysts to do far more sophisticated analyses than these simplified examples might suggest. The next section summarizes the HEC-FDA approach to expected annual damage calculations. The Corps state-of-the-art approach to risk analysis of the uncertainties in flood damage reduction studies is found there and in the supporting guidance.

5.8 Risk Analysis in Expected Annual Damages

To further illustrate the role of uncertainty in the expected annual damage calculation a new example using HEC-FDA outputs is introduced in this section. This example demonstrates, in a general manner, the Corps current policy as applied via HEC-FDA. Notice that the Corps' guidance tends to use error and uncertainty interchangeably. This reflects a matter of convenience more than one of substance. Suppose, for example, we are 95 percent confident the mean first floor elevation is between 6 and 8 NGVD and the expected value is 7. This would be one way to express uncertainty. Equivalently, we could say the mean value is 7 NGVD with an error of plus or minus 1 foot. HEC-FDA tends to use the latter method to express uncertainty, adding or subtracting an error term from a best estimate. HEC offers a course in the use of FDA and other tools.

HEC-FDA Example

The four expected annual damage relationships are presented below for a sample reach using the HEC-FDA model. These are the kinds of graphic reports available from HEC-FDA. They are presented here to conclude the discussion of uncertainty in the expected annual damage calculation.

The HEC-FDA computer program was developed to assist Corps staff in analyzing the economics of flood-damage-reduction projects. The program:

- Stores hydrologic and economic data necessary for an analysis;
- Provides tools to visualize input data and results;
- Computes Expected Annual Damage and Equivalent Annual Damages; and
- Implements the risk analysis procedures described in EM 1110-2-1619.

Note: This section touches on the latter two points.

The HEC-FDA figures below show the uncertainty in the three input relationships. They are oriented a little differently, so take a moment to examine them. Carefully look at the axes on each individual figure, notice the metrics. Note that the various curves in a single graphic represent median values and plus or minus one or two standard deviations. There are no percentiles shown. Notice that the damage-frequency relationship is showing relationships for numerous kinds of damages, rather than showing the uncertainty in the model output.

Understand that each of the graphics below (Figure 52, Figure 53, Figure 54, Figure 55) represents a three dimensional figure. Rising out of the page, centered over the median value and tapering off toward the upper and lower limits of the curve is a distribution that captures what HEC-FDA considers the key uncertainties for a flood damage reduction study. This is just as has been described earlier.

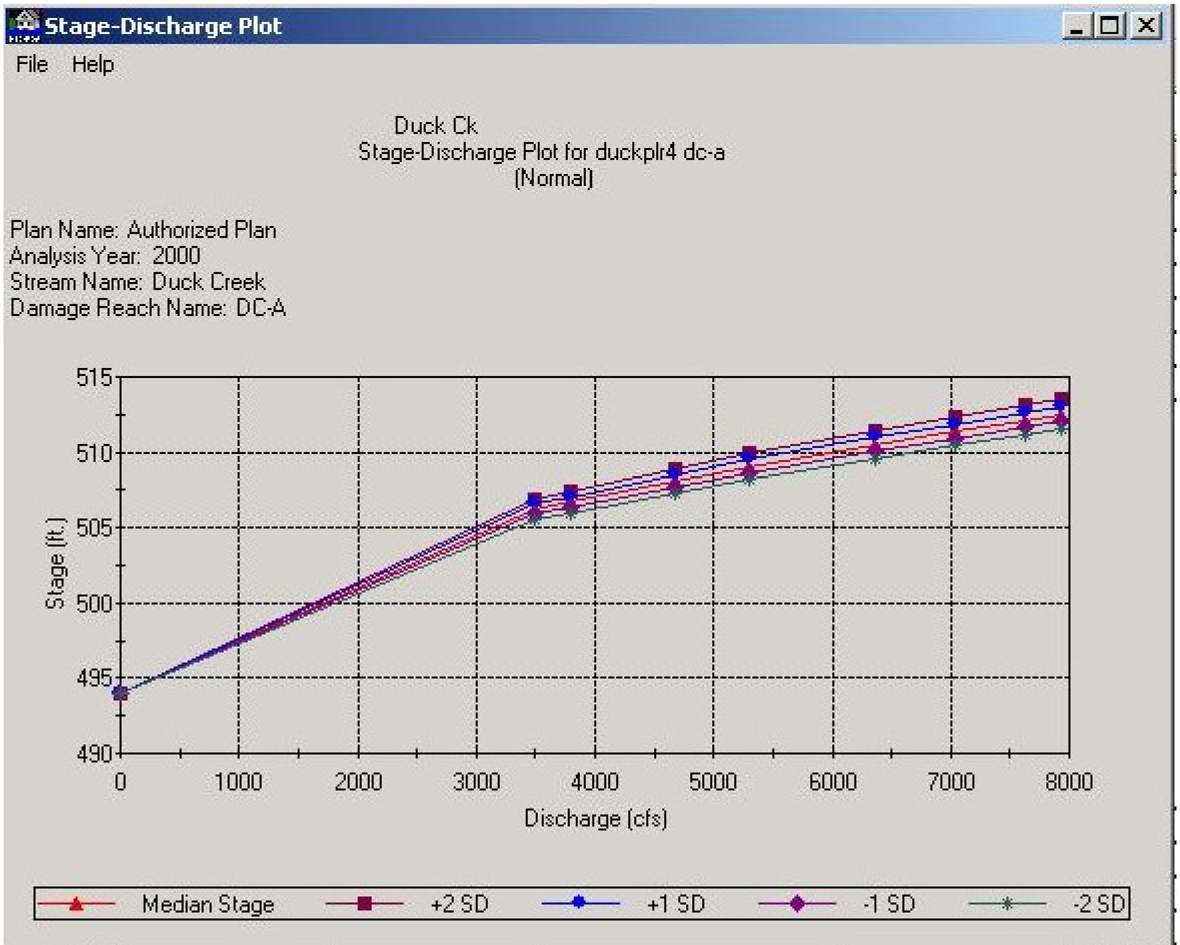


Figure 52: Duck Creek Stage-Discharge Plot for duckplr4 dc-1 (Normal)

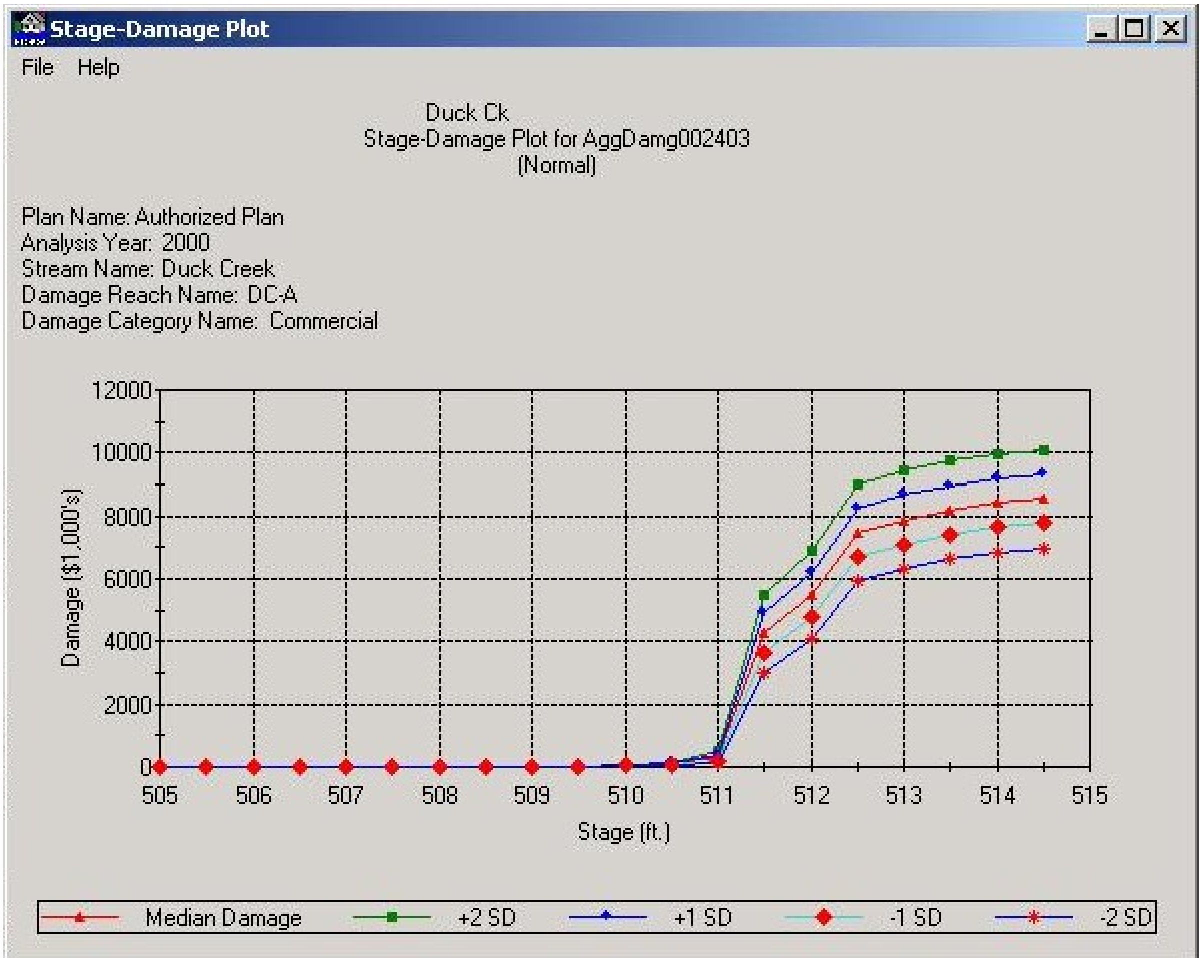


Figure 53: Duck Creek Stage-Damage Plot for AggDamg002403 (Normal)

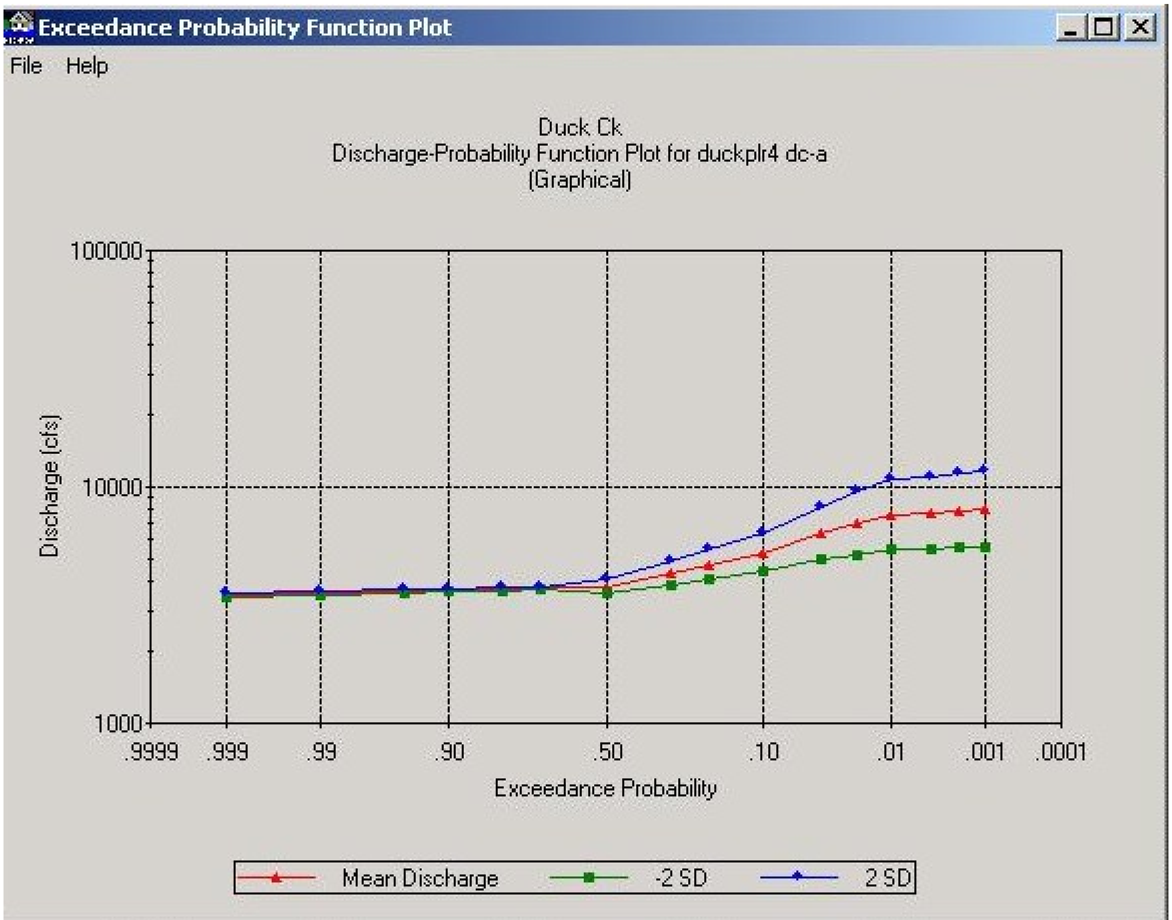


Figure 54: Duck Creek Discharge-Probability Function Plot for duckplr4 dc-1

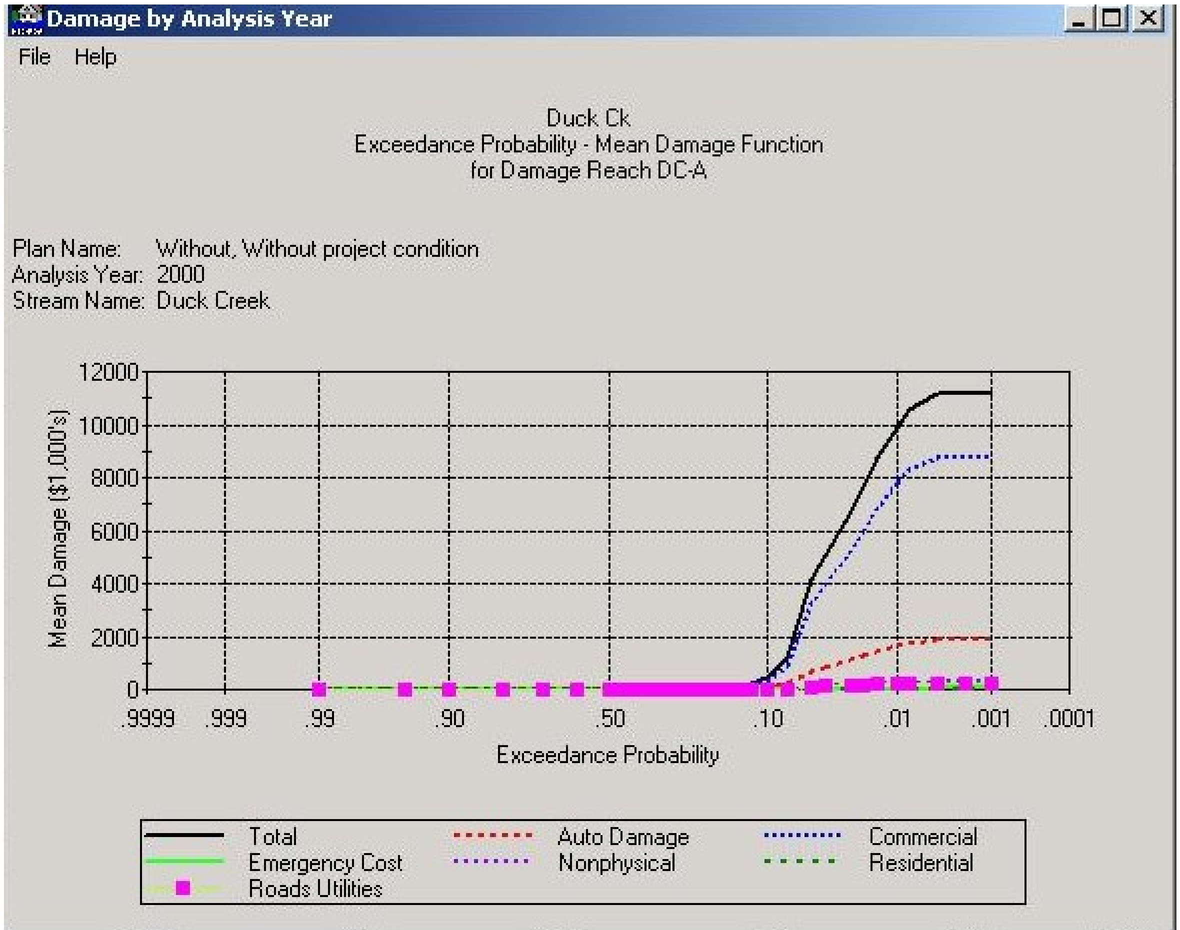


Figure 55: Duck Creek Exceedance Probability – Mean Damage Function for Damage Reach DC-A

Stage-Damage Function

A stage-damage function is usually developed by a process similar to the following for residential damages:

- Identify and categorize each structure in the study area based upon its use and construction.
- Establish the first-floor elevation of each structure using topographic maps, aerial photographs, surveys and/or hand levels.
- Estimate the value of each structure using real estate appraisals, recent sales prices, property tax assessments, replacement cost estimates or surveys.
- Estimate the value of the contents of each structure using an estimate of the ratio of contents value to structure value for each unique structure category.
- Estimate damage to each structure due to flooding to various water depths at the structure's site using a depth-percent damage function for the structure's category along with the value from Step 3.

- Estimate damage to the contents of each structure due to flooding to various water depths using a depth-percent damage function for contents for the structure category along with the value from Step 4.
- Transform each structure's depth-damage function to a stage-damage function at an index location for the floodplain using computed water-surface profiles for reference floods.
- Aggregate the estimated damages for all structures by category for common stages.

This process is modified by HEC-FDA to address the uncertainty in flood damage reduction studies by using probability distributions to describe the uncertainty or errors in estimating (a) the first-floor elevation of the structure; (b) the percent damage to a structure for a given water depth; (c) the structure value; (d) percent damage to the contents for a given water depth and (e) the structure-to-content value ratio. Each of these errors is sampled and combined to develop a description of the overall uncertainty or error. EM 1110-2-1619 guidance on several of these is summarized in the following pages.

Structure Value

Structure value is a critical parameter of the stage-damage function. It is used to directly determine the damage to the structure and indirectly to determine damage to the structure's contents. Depreciated replacement value is the appropriate measure of structure value for Corps studies. There are several acceptable methods for estimating this value (see Table 6-3 of EM 1110-2-1619).

To develop a description of the error or uncertainty in structure value, one of the following may be used:

Professional judgment. Each structure's value is estimated by an expert in real-property valuation and is expressed as a range or as minimum and maximum values. From these values a probability model (i.e., a distribution) can be chosen to represent the uncertainty about the structure's true value. Uniform, triangular and normal distributions are mentioned in EM 1110-2-1619.

Sampling to fit a distribution. A sample of structure values, stratified appropriately by structure category, is drawn from the real estate assessments and is used to estimate statistics that describe sample errors in each category. For example, the mean value of a one story individual house with a basement and its standard error can be estimated. This is an example of a sampling distribution. Alternatively, these statistics can be used to estimate the parameters of a probability distribution that describes not the mean value, but the individual values of such homes. For example, the mean and standard deviation of the logarithms of the sample values can be used to define a log normal distribution of structure values.

Content-to-Structure Value Ratio

Residential content value is commonly estimated as a fraction of the structure value. This approach is used by residential casualty insurers in setting rates and content coverage for homeowners insurance. The value of contents found in any one structure type, however, is highly variable. Wealth, income, preferences, lifestyle, tastes and a variety of other factors comprise the system that produces this content variability.

EM 1110-2-1619 presents means and standard deviations of content-to-structure value ratios based on large samples of Flood Insurance Administration (FIA) claims records. Although these nationwide statistics are not appropriate for all cases, they can be useful in developing a probability distribution of errors when better data are not available.

First-Floor Elevation

The first floor elevation of the structure is a critical input for constructing a stage-damage curve. The means of establishing this datum vary in their accuracy. Field surveys with instrumentation or hand levels are common. Aerial surveys or topographic maps are also used. EM 1110-2-1619 provides an estimate of the elevation errors for these methods. Light Detection and Ranging (LiDAR) uses laser technology to gather elevation data. This information can be used to estimate the parameters of a probability distribution of errors.

Stage-Discharge Function

Stage-discharge uncertainty may stem from any of the factors affecting the stage-discharge relationship including, but not limited to: bed forms, water temperature, debris or other obstructions, unsteady flow effects, variation in hydraulic roughness with season, sediment transport, channel scour or deposition, or changes in channel shape during or as a result of flood events. In some instances, uncertainty might be introduced into the stage-discharge curve due to measurement errors from instrumentation or the method of flow measurement, waves and other factors in the actual measurement of stage and discharge. Models are limited by the inherent inability of the theory to model *exactly* the complex nature of the hydraulic processes. Data used in the models are also not exact, introducing errors in the model geometry and coefficients used to describe the physical setting. In addition, many of the factors which determine stage-discharge uncertainty and which are estimated for modeling purposes are time-dependent, both seasonally as well as during a flow event. Many of the factors are also spatially variable, both laterally and longitudinally in the channel and associated floodplain. In general, the more complex the flow conditions, the greater the need to use models that replicate the significant physical processes.

With so many potential sources of uncertainty, several different methods have been developed to estimate the stage-discharge uncertainty for a stream reach. The most applicable method will depend on the data available and the method used in project studies. Stage-discharge uncertainty can be evaluated for several contributing factors or for each factor individually. When the factors are analyzed separately, care must be taken to ensure that the resulting uncertainty from combining the factors is reasonable.

Whatever the method used to quantify the uncertainty, the measure used to define the uncertainty of the stage-discharge relationship is the standard deviation. Stage residuals, i.e., the difference between observed values and rating function values, provide the data needed to compute uncertainty. One approach to estimating stage uncertainty that can always be used is to estimate the upper and lower bounds on stage for a given discharge and convert the stage range to the needed uncertainty statistic, i.e., standard deviation, by dividing the range by 4.

For example, 95 percent of the error range would be encompassed by stages that are two standard deviations above and below the mean. Professional judgment could thus be applied to estimate the *reasonable* upper and lower bounds of stage, and the standard deviation estimated as the total range divided by 4. Sensitivity analysis in which reasonable likely combinations of upper and lower bound estimates of model parameter values are used to obtain a range of predicted stages for a given discharge could augment or serve as an alternative to the range determined from professional judgment.

The graph shown at the top of the page above summarizes a stage-discharge uncertainty analysis consistent with the examples of Chapter 5 of EM 1110-2-1619. Note that the objective is to calculate uncertainty in stage, not discharge. That is, for a given discharge, the various stages that flow might reach are identified.

Discharge-Frequency Function

The EM 1110-2-1619 guidance for the discharge-frequency curve was summarized in the discharge-frequency discussion on the previous page.

Guidance

- Risk Analysis for Evaluation of Hydrology/Hydraulics, Geotechnical Stability and Economics in Flood Damage Reduction Studies
- ER 1105-2-101: Planning - Risk Analysis for Flood Damage Reduction Studies

- Engineering and Design - Risk-Based Analysis for Flood Damage Reduction Studies EM 1110-2-1619
- Engineering and Design - Hydrologic Frequency Analysis EM 1110-2-1415
- Engineering and Design - River Hydraulics EM 1110-2-1416
- Flood-Runoff Analysis EM 1110-2-1417
- Hydrologic Engineering Requirements for Flood Damage Reduction Studies EM 1110-2-1419

5.9 Engineering Performance of Flood-Damage Reduction Plans

This manual provides detailed information about how the Corps measures the contributions of a project to national economic development. This is only one measure of project performance. Another important measure is the project's engineering performance. It was once common practice to speak of the level of protection provided by a plan. Flood damage reduction projects were commonly said to provide 100-year protection. This, of course, was confusing and misleading to the lay public who, understandably, often took it to mean they were *guaranteed* to be free from flooding for 100 years. This practice was modified to say that a project provides protection from a flow that has a 1 percent or less chance of occurring in any 1 year. But even this statement overlooked the effects that uncertainty could have on the engineering performance of a project.

Engineering performance is currently measured using any or all of the four indices below. These are: expected annual exceedance probability, long-term risk, consequences of capacity exceedance and conditional probability. Each is discussed briefly below. For a more complete discussion of these indices see EM 1110-2-1619.

Expected Annual Exceedance Probability

The expected annual exceedance probability (AEP) measures the annual likelihood of a flow exceeding a hydraulic target. For example, the annual exceedance probability for a 20-foot levee might be 0.01. This means there is a 1 percent chance (0.01 probability) that, in any given year, the river will reach a stage that exceeds the elevation of the top of the levee. Historically, this value was obtained by simply referring to the discharge-frequency and stage-discharge functions. For example, to find the annual exceedance probability of a levee with a top elevation of 20 feet, one would obtain a discharge corresponding to this stage. The exceedance probability corresponding to this discharge would be obtained from the discharge frequency curve.

Discharge (000's)	**Feet** (NGVD)	**Exceedance Frequency** (%)
228	1	2.000
242	2	1.217
259	3	0.893
280	4	0.683
295	5	0.503
308	6	0.373
325	7	0.298
342	8	0.209
358	**9**	**0.150**
380	10	0.115
400	11	0.082
422	12	0.065
442	13	0.048
464	14	0.035
--	15	0.001

Figure 56: Expected Annual Exceedance

Calculate the annual exceedance probability for a levee 9 NGVD using the data from the EAD example reproduced above (Figure 56). Step 1 is to ascertain the flow that corresponds to a height of 9 NGVD. That is 358,000 cfs. Step 2 is to look up the annual exceedance frequency that corresponds to 358,000 cfs. In the table here, that probability is 0.15 percent, or 0.0015. Thus, in any given year, there is a 0.0015 probability that a flow in excess of 9 NGVD will occur.

If the discharge-frequency and stage-discharge functions are not known with certainty, then the annual exceedance probability cannot be known with certainty either. In a risk-based flood damage reduction study, the estimation of the annual exceedance probability must include an uncertainty analysis. Annual-event sampling or function sampling can be used for this analysis, depending on which method was used for the expected annual damage computation.

The basic approach is as follows:

- Randomly generate a maximum annual discharge.
- An error adjustment should then be randomly sampled and added to the maximum annual discharge.

- Use this discharge value to identify the corresponding stage from the median rating curve.
- Randomly sample a rating curve error term and add it to the stage in order to obtain a height corresponding to the generated maximum annual discharge. (This value has now been adjusted using error terms to account for the uncertainty associated with the discharge and its stage).
- Compare the resulting value to the top of protection and the top of protection is either exceeded (1) or not (0).
- Repeat this process a large number of times (*n*).
- Divide the number of times the top of protection is exceeded (x) by *n* to obtain an estimate of the annual exceedance probability.

The data generated in this fashion will support the estimation of a classical statistical confidence interval around this estimate of the probability of exceeding the levee height.

Long-Term Risk

Long-term risk is an estimate of the likelihood that the level of protection will be exceeded one or more times in a fixed number of years. For example, one can estimate the probability of a project with an annual exceedance probability of 0.01 being exceeded one or more times in 50 years (project life), 30 years (a typical mortgage duration), 10 years (the time a person expects to live in a neighborhood), and so on. To see how simple it is to calculate this probability, download and run Long Term Risk Excel File.

Long-term risk is a useful index for communicating plan performance because it provides a measure of probability of exceedance with which the public can identify. It can also help expose common misconceptions about flooding probabilities. For example, there is a 63 percent chance there will be one or more floods over a 100 year period in an area with a project that has an annual exceedance probability of 1 percent annually. There is a 26 percent chance a person who lives 30 years in a floodplain with protection that provides a 1 percent annual exceedance frequency will be flooded one or more times. Correspondingly, there is a 74 percent chance the homeowner will experience no floods in 30 years. This information is useful to help the public understand the randomness of hydrologic events and to understand that it is not unusual for "protected" property to be flooded. An excellent illustration of the concept of long-term risk is provided by Harris County in Learn about Floodplains.

Conditional Annual Non-Exceedance Probability

It is also useful to know the probability that a specific event will not exceed the top of protection. That is, given that a specific event occurs, what is the probability that event will be contained by a given level of protection. In the language of statistics this is a conditional probability and this value is called the Conditional Annual Non-Exceedance Probability (CNP) by the Corps.

Suppose the plan calls for a levee built to a height of 20 feet. Even if we know that it has an annual exceedance probability of 0.01, there is still some uncertainty about the height that a flow of any given exceedance frequency will attain. The CNP is intended to indicate the probability that a specific exceedance frequency will not exceed the top of protection. So, for example, if the conditional non-exceedance probability of a proposed 20 foot levee is 0.75 for a 0.002 probability event, we can say that if the plan is implemented, there is a 75% chance that the stage of a 0.002 probability event will not exceed 20 feet.

The conditional non-exceedance probability is a useful indicator of a project's performance because of the uncertainty in discharge-probability and stage-discharge estimates. This index provides a useful evaluation criterion when the CNP for numerous events is calculated for several plans.

It can be particularly useful to decision makers to use this index to indicate how a plan might perform with a recurrence of one or more historical events, including the flood of record (FOR). Knowing the probability that the flood of record will be contained (non-exceedance) by the project is a very useful piece of information.

Calculating the CNP requires specification of:

- The performance target as a stage (commonly the maximum stage possible before any significant damage is incurred).
- One or more critical events – like the FOR or Standard Project Flood (SPF) – should be selected to provide information for decision making.
- The calculation method depends on how the target event is specified and the method of sampling used. In general the calculation requires the following: (1) discharge-frequency function with the uncertainty described by a probability function; (2) stage-discharge function with the uncertainty described by a probability function; and (3) geotechnical performance function. Additional information on the calculation is available in Chapter 3 of EM 1110-2-1619.

Consequences of Capacity Exceedance

Regardless of the size a flood damage reduction project, the probability that its capacity will be exceeded is never zero. In other words, zero risk of flood damages is never going to be a realistic option for any community. Consequently, it is important to analyze and describe the consequences of a flood event that does exceed a project's capacity. One part of this analysis should be an analysis of residual expected annual damages, i.e., the with-project condition expected annual damages. Another part of the analysis might include consideration of specific capacity exceedance scenarios.

Levee Failures

The measures above describe the risks associated with levee performance in a variety of ways. None of these measures is intended to address situations where levees fail to perform as designed.

The figures in Figure 57 to the right (courtesy of The Hawk Eye, Burlington, Iowa) show a levee with an animal burrow in it. As the river rises, the levee can become saturated. The high water in the middle picture shows water moving through the levee softening and weakening its foundation. High water increases the force against the levee.

Erosion of the foundation of the levee can result in a *boil.* A boil is an area on the dry side that begins to slide away from the base of the levee. If left unchecked, the levee could eventually collapse.

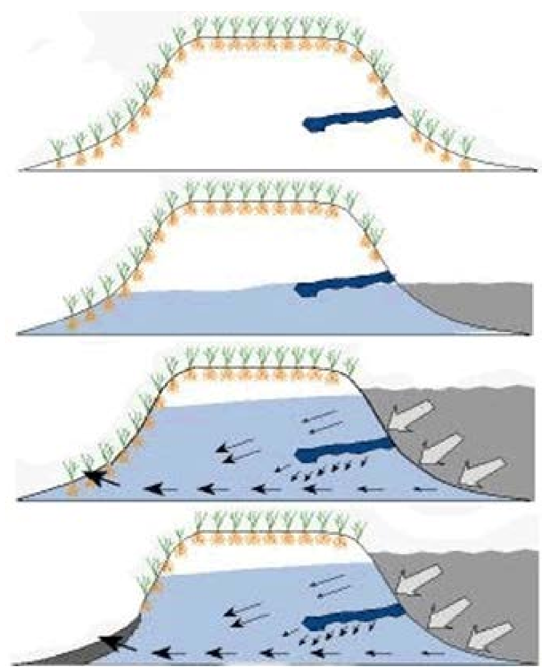


Figure 57: Levee with an Animal Burrow (courtesy of The Hawk Eye, Burlington, Iowa)

This is just one of many possible modes of failure. None of these are addressed by the measures above. An assessment of the risk of this or another mode of failure is typically not a part of the NED analysis of a new project. Such analysis may well be of interest for a major rehabilitation study, however. It is a different style of risk assessment than required for a flood damage reduction study.

5.10 Benefit-Cost Analysis

The net benefits produced by a flood damage reduction project are uncertain for the reasons discussed in this topic. The best economic analysis will characterize the full range of potential project net benefits as honestly and objectively as possible. Currently, this is difficult to do. Although there is a requirement to use risk analysis to estimate benefits, there is no corresponding requirement to use risk analysis to assess project costs. This asymmetry in analytical requirements limits the economist's ability to present an accurate picture of the total surplus associated with a project.

Cost Estimation

There is no current requirement to use risk analysis to estimate project costs. Research conducted by the Corps' Institute for Water Resources (IWR) has repeatedly shown the feasibility of using risk analysis to estimate costs. For examples, see Ecosystem Restoration Cost Risk Assessment and Risk Analysis Framework for Cost Estimation.

Although a careful consideration of the risks associated with cost estimation is beyond the scope of this manual, the attached files present a brief overview of the use of the Monte Carlo process in estimating project costs. Cost Estimate 1; Cost Estimate 2.

A sample cost estimate exercise developed for use in training Corps personnel in the use of risk analysis for cost estimation is attached. The interested reader can download and work the exercise. It requires xls software with the Palisade @Risk add-in. A free trial copy of @RISK Decision Suite is available from Palisade.

Although cost estimates are to be unbiased and accurate, the reward system for cost estimators is asymmetric. Underestimating a cost presents more problems than overestimating a cost. Some people would argue that cost estimation tends to be conservative in the sense that the estimator, given a choice between underestimating or overestimating, would err on the side of overestimating, all other things equal. If this is true, it could have potentially significant impacts on the estimation of net benefits by distorting the magnitude and likelihood of these benefits as illustrated below.

Net Benefits

Using the without- and with-project conditions presented earlier in the manual, 10,000 calculations of benefits accruing to an 8-foot wall were computed and the results are presented in Figure 58 below. Notice that the potential uncertainty in the benefit estimate is reasonably well characterized by this probabilistic approach.

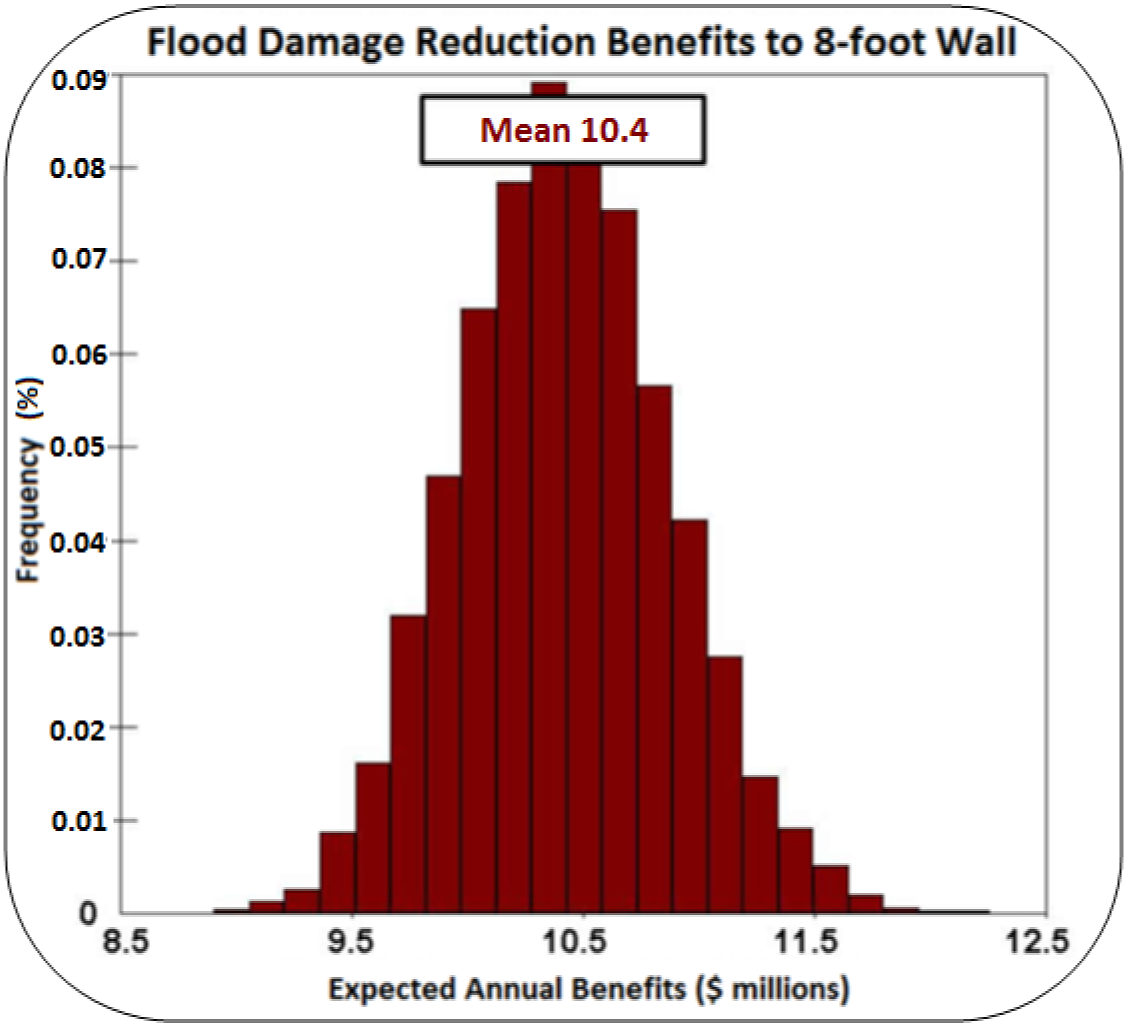


Figure 58: Flood Damage Reduction Benefits to 8-FOOT Wall

Expected annual benefits could be as low as $8.9 million or as high as $12.3 million. The expected value is $10.4 million.

To illustrate the potential problem that could result when benefits are estimated probabilistically and costs are not, consider a hypothetical project with average annual costs of $10.5 million. Net benefits based on the point estimate costs and the expected value of benefits is -0.1 million with a benefit-cost ratio of 0.99. This does not bode well for the economic feasibility of the project. About 42 percent of the project benefit estimates are in excess of $10.5 million.

Now let us consider costs. They have not been estimated using the same probabilistic risk analysis techniques as benefits.

There is indeed uncertainty that the cost estimator must address. Without worrying about how that is done, let us suppose there is a hypothetical distribution of cost estimates that reflects the uncertain costs in much the way the distribution above represents the possible benefit values. This distribution is shown in Figure 59 below. Now further suppose that the pressure to estimate costs conservatively pushes the estimator to values that are above the mean as shown here.

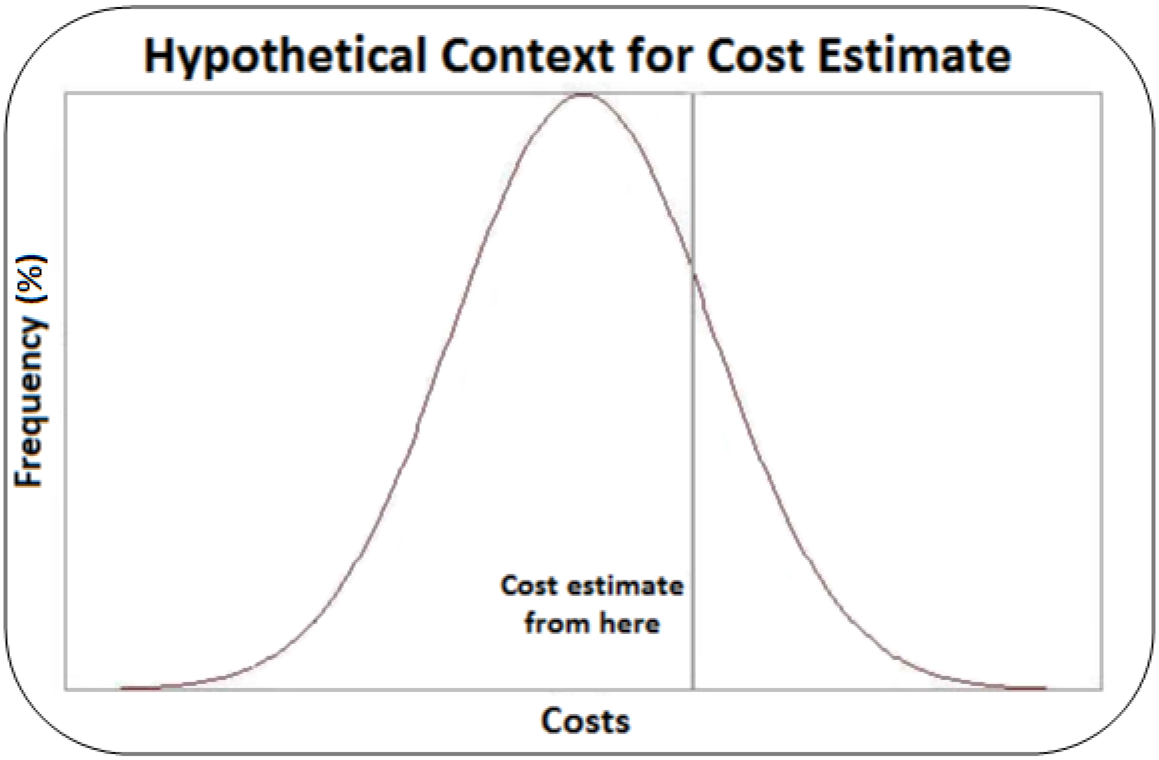


Figure 59: Hypothetical Context for Cost Estimate

The practical and immediate significance of this is that the point estimate of benefits is the expected value, while the point estimate of costs may be something above the mean. Absent a risk analysis of costs, it is not possible to say what the likelihood of the actual estimate is. But to compare a 50th percentile benefit estimate to, for example, an 80th percentile cost estimate does not provide decision makers with an accurate picture of the project's economic efficiency.

Imagine that benefits and costs have both been estimated using probabilistic risk analysis techniques. For an example, see the attached video demonstration. Figure 60 below provides a more realistic way to approach benefits and costs. The figure shows benefits as the short and squat (brown) distribution with costs as the tall and lean (green) distribution. Average annual benefits are measured in millions of dollars.

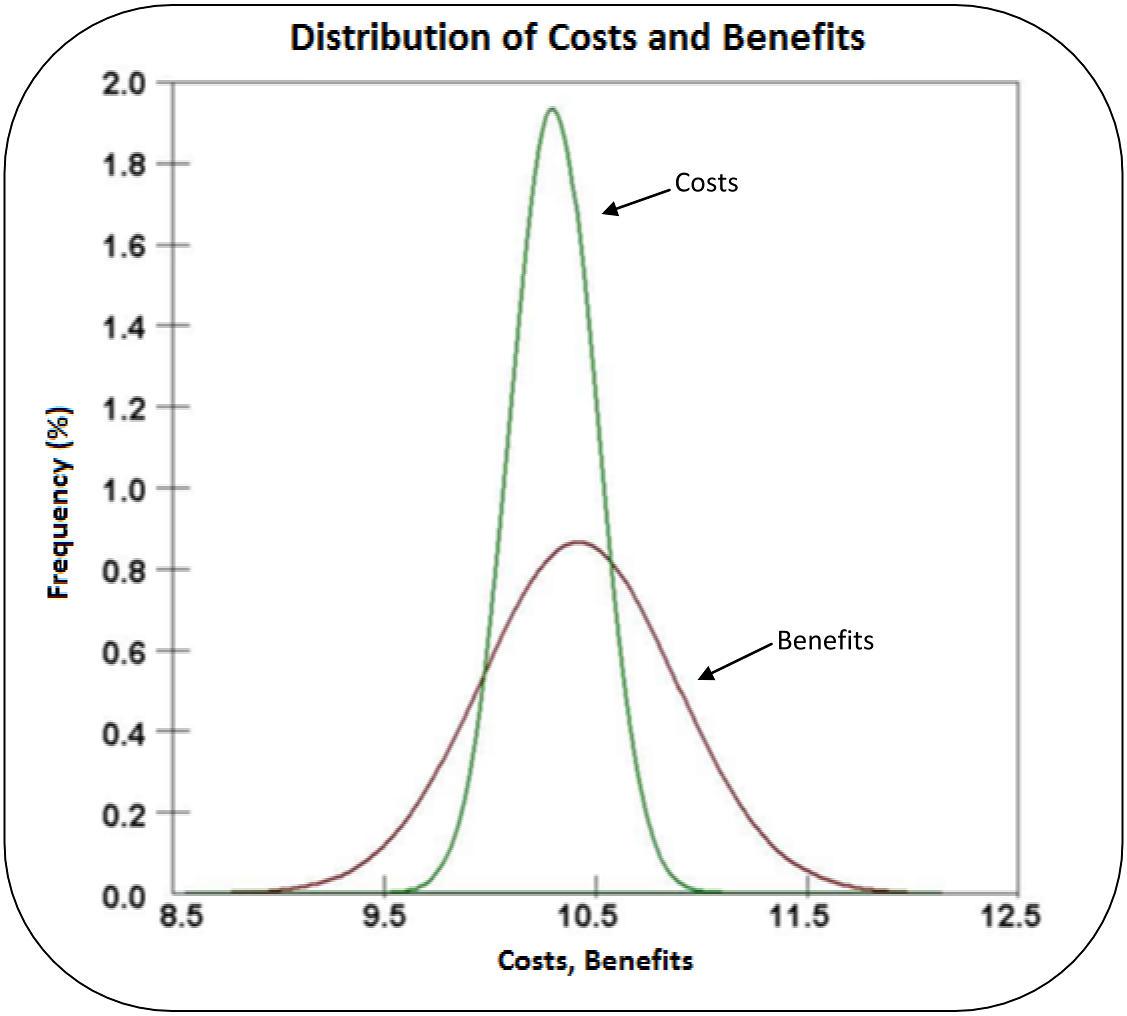


Figure 60: Distribution of Costs and Benefits

A project previously thought to have a benefit-cost ratio slightly below 1 turns out as shown in the distribution of net benefits below (Figure 61). The shaded area depicts the likelihood that this project will yield positive net benefits, almost 60 percent in this case. The expected net benefits have gone from -$0.1 million to +$0.1 million. This is a significantly different perspective than can be gained from a point estimate of costs with an unknown likelihood of being exceeded.

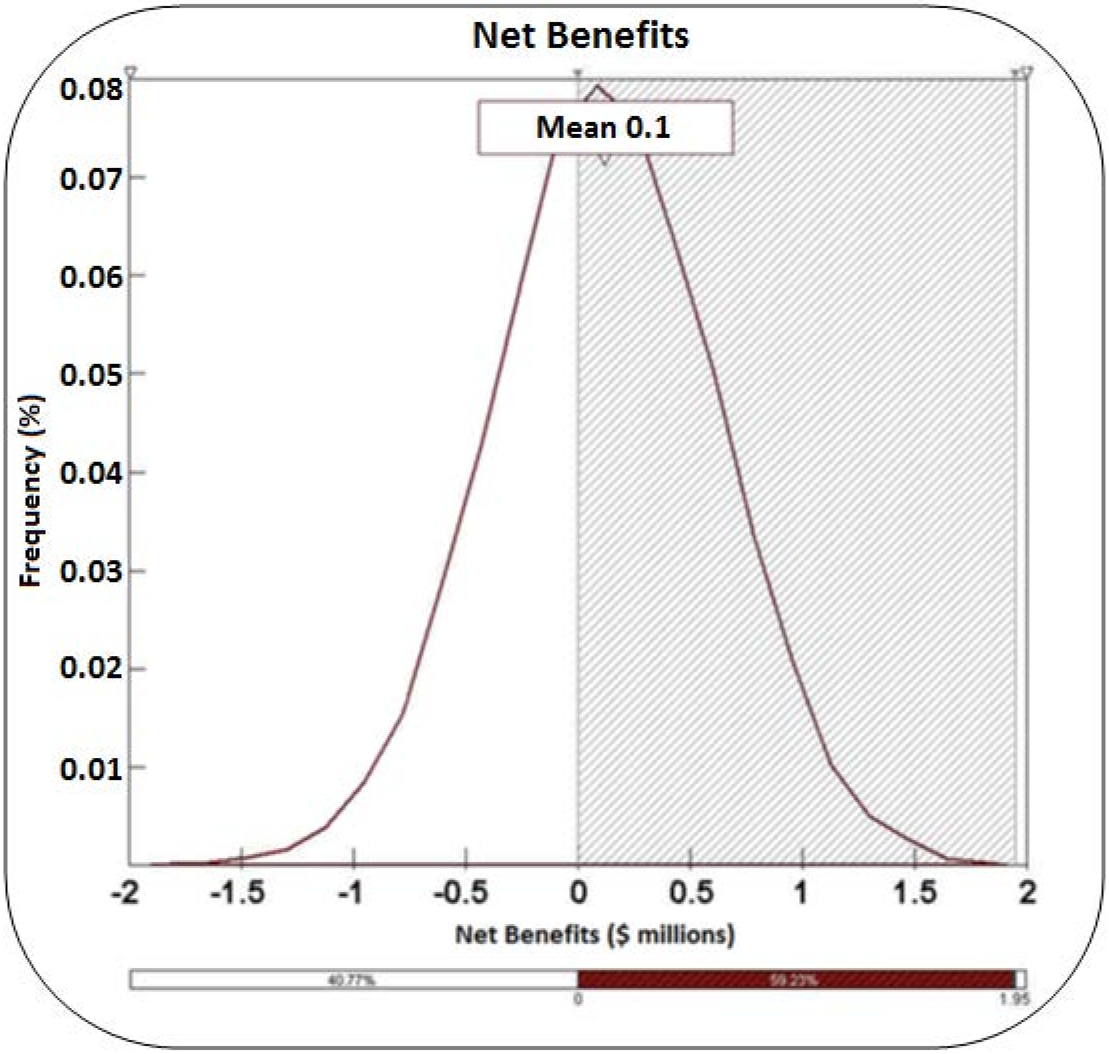


Figure 61: Net Benefits

It is important to note this anecdotal example was contrived specifically to make a point, but both the contrivance and the point are reasonable. The only way to ensure that such problems do not occur with estimates of net benefits is to account for the uncertainties in costs using a probabilistic estimate of costs.

Chapter 6: Non-Structural Alternatives

6.1 Introduction

Section 73 of the 1974 Water Resources Development Act (WRDA) requires consideration of nonstructural alternatives in flood damage reduction studies:

> *In the survey, planning, or design by any Federal agency of any project involving flood protection, such agency, with a view toward formulating the most economically, socially, and environmentally acceptable means of reducing or preventing flood damages, shall consider and address in adequate detail nonstructural alternatives, including measures that may be implemented by others, to prevent or reduce flood damages. Such alternatives may include watershed management, wetlands restoration, elevation or flood proofing of structures, floodplain regulation, relocation, and acquisition of floodplain lands for recreational, fish and wildlife, and other public purposes.*

Nonstructural measures can be considered independently or in combination with structural measures. These types of measures reduce flood damages without significantly altering the nature or extent of flooding. They do this by changing the use of the floodplains or by accommodating existing uses to the flood hazard. Examples of nonstructural measures include flood proofing, relocation of structures, flood warning/preparedness systems and regulation of floodplain uses.

Benefit estimation techniques for nonstructural measures differ from those for structural measures discussed earlier in this manual. This chapter also provides information on the details of nonstructural alternatives, the difficulties encountered in estimating benefits for nonstructural alternatives, current benefit estimation techniques, and some additional policy considerations for nonstructural benefit estimation. The National Nonstructural Floodproofing Committee provides access to many useful nonstructural resources.

6.2 Non-Structural Flood Damage Reduction Measures

Nonstructural flood control measures are most often defined by a list of examples. The P&G [1.6.1(f)(1)] described them as "complete or partial alternatives to traditional structural measures. Nonstructural measures include modifications in public policy, management practice, regulatory policy and pricing policy."

Although defining nonstructural measures as those that are not structural may be common, it is not very helpful. However, if we consider structural measures to be those that are directed at modifying the flood hazard, then we can define nonstructural measures as those that modify the impacts of the flood hazard. Structural measures keep the floods away from people and damageable property; nonstructural measures keep the people and damageable property away from the floods.

The impacts of the flood hazard can be modified by a) reducing a community's susceptibility to flood damage and disruption, or b) reducing hazardous uses of the floodplain. Examples of these two broad approaches are discussed below. There are nonstructural actions that can be taken between floods, during floods and after floods.

Policy History of Nonstructural Measures

- Flood Control Act of 1938 – land acquisition authorized
- H.D. 465 (1966) – alternative methods encouraged
- EO 11296 (1966) – flood loss on Federal lands must be considered
- National Flood Insurance Act (1968) – created NFIP
- EC 1120-2-40 (1968) – treatment of nonstructural alternative
- EC 1120-2-49 (1969) – progress in treatment of nonstructural measures
- EC 1120-2-117 (1970) – alternative in flood-related planning
- 1973 Flood Disaster Protection Act – required participation in NFIP
- Principles and Standards (P&S, 1973) – planning process to include nonstructural measures
- Section 73 WRDA (1974) – required consideration of nonstructural measures for flood control
- ER 1105-2-351 (1975) – procedures for Ned benefits including nonstructural measures
- ER 1105-2-200 (1975) – no multi-objective bias toward structural or nonstructural measures
- EO 11988 (1977) – agency role in floodplain management
- President's Policy (6/6/78) – greater utilization of nonstructural measures
- ER 1105-2-353 (1979) – benefits and costs of evacuation and relocation
- ER 1165-2-26 (1979) – implementation of EO 11988
- Water Resources Council (1979) – A Unified National Program for Floodplain Management
- Policy Guidance for Nonstructural Measures (10/15/1979)
- Revisions to P&S (1979) – nonstructural plan required
- Policy in Land Acquisition for Nonstructural (4/12/1982)
- P&G (1983)
- IWR Research Report 85-R-1 (1985) – Assessment of the economic benefits from flood damage mitigation by relocation and evacuation

Reducing Community Susceptibility to Floods

Emergency Preparedness

Emergency preparedness is largely a planning function. Preparing for floods by developing flood response plans can reduce damages and disruption caused by flooding for businesses, homes, government entities and the community-at-large. Identifying critical equipment, records and supplies prior to the onset of a flood can aid the recovery of operations following a flood. Developing specific flood fighting and evacuation plans will enhance the likelihood of success for these activities. Implementing these emergency operations is usually the responsibility of management, the homeowner, agency heads, elected officials or other persons with the authority to implement such plans. To view an in-depth guide to citizen preparedness, please see FEMA's "Are you Ready?"

Flood Forecast and Warning

Forecasting floods and providing a warning to the community provides the opportunity to respond. This response might be enacting formal emergency response plans or directing ad hoc actions to reduce damages and save lives. For an example see the Susquehanna River Basin Commission.

Flood Insurance

The National Flood Insurance Program (NFIP) provides owners and renters of flood-prone property an opportunity to insure against some flood losses. Participation in the NFIP by communities is voluntary, although some states now require NFIP participation as part of their floodplain management programs. Flood insurance is also required by lending institutions that are federally regulated or federally insured.

Nearly 20,000 communities across the U.S. and its territories participate in the NFIP by adopting and enforcing floodplain management ordinances to reduce future flood damage. In exchange, the NFIP makes federally backed flood insurance available to homeowners, renters and business owners in these communities.

Flood damage is reduced by nearly $1 billion a year through partnerships with communities, the insurance industry and the lending industry. Further, buildings constructed in compliance with NFIP building standards suffer approximately 80% less damage annually than those not built in compliance, and every $3 paid in flood insurance claims saves $1 in disaster assistance payments.

The NFIP is self-supporting for the average historical loss year, which means that operating expenses and flood insurance claims are not paid for by the taxpayer, but through premiums collected for flood insurance policies. The NFIP has borrowing authority from the U.S. Treasury for times when losses are heavy; however, these loans are paid back with interest.

Flood Proofing

Flood proofing consists of activities to modify buildings, their sites, or their contents to keep water out, or to reduce the damage caused by water entry. Dry flood proofing consists of activities designed to keep water out of a building, i.e., the inside stays dry. Wet flood proofing consists of measures designed to limit the damage done by water, usually by using water resistant materials and construction techniques. New and existing structures can be flood proofed.

Some of the more common flood proofing measures include:

- Backflow valves
- Closures on doors, windows, stairwells and vents–they may be temporary or permanent
- Elevating structures via landfill, walls, posts, piers, jacks and beams
- Rearranging or protecting damageable property–e.g., relocate or raise utilities
- Ring walls and levees around structures and utilities
- Sump pumps and sub-drains
- Water resistant material; metal windows, doors and jambs; waterproof adhesives; sealants and floor drains

Information and Education

Officials, planners and the public must first be educated about the existence and nature of a flood hazard. Floodplain mapping is a critical tool for this task. Home buyers should be made aware of hazards that may exist where they intend to buy. Once generally aware of the nature of the hazard, people need information about how to respond to the threat and reality of flooding.

Modifying Equipment

Equipment may be modified for use in the floodplain in ways that differ from traditional flood proofing. Chief among these are modifications that enable the quick removal of equipment for evacuation. Electrical and mechanical equipment may be modified so that highly skilled personnel are not required for removal. Other examples of measures that can be taken to reduce susceptibility to floods include providing easy and direct access to critical equipment, and keeping equipment for lifting and transporting heavy equipment out of harm's way is a third measure that can be taken.

Relief, Recovery and Rehabilitation

Flood relief, recovery and rehabilitation are closely allied to emergency preparedness. In the aftermath of a flood the speed with which a community recovers depends to a great degree on the extent to which they were prepared for the flood. The identification of actions, equipment, materials and personnel needed to clean-up, repair and reinstall equipment can speed the return to normal operations. Stockpiling the necessary materials and color-coding or otherwise identifying critical connections for electrical and mechanical equipment can further ensure a speedy recovery. The implementation of an emergency response plan as part of a disaster preparedness program can mobilize relief agencies and donations to the best possible use of the community.

Reducing Hazardous Uses of Floodplains

Limiting and directing the development that takes place in the floodplain is another approach to mitigating the impacts of a flood.

Building Codes

Building codes and construction codes regulate the materials used in construction, site preparation and construction method. Some examples of these measures include requiring windows and jambs that do not warp when inundated, water resistant materials (such as metal doors), waterproof adhesives on tiles, and the raising and protecting of utilities.

Design and Location of Services and Utilities

State and local governments can direct development to low risk areas. Discretion can be used in providing services that spur development. By carefully evaluating the extension of roads and utilities, the locations of schools, libraries, hospitals and the like, future development patterns can be influenced.

Evacuation

Evacuation in the context of floodproofing refers to the purchase of structures and other floodplain improvements for the purpose of permanently removing them from the floodplain. Evacuation generally implies the razing or abandonment of structures and other improvements.

Housing Codes

Housing codes set minimum standards for the occupancy of residential units. Special standards can be specified for houses occupying flood prone areas. Housing codes affect existing houses whereas building codes affect future houses.

Public Acquisition

Public acquisition is the purchase of floodplain lands, flow easements or development rights to reduce existing or limit future flood damages. Lands, particularly in the floodway, can be purchased to maintain the carrying capacity of existing floodplains.

Relocation

Relocation is the permanent removal of structures or other improvements from the floodplain, resituating them on alternative, flood free sites. Relocations affecting residents and businesses are governed, in part, by the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (P.L.91-646).

Sanitary and Well Codes

Sanitary and well codes establish minimum standards for and protect the water supply and wastewater collection systems from contamination and damage from floods. Codes can prevent overloaded, poorly designed, improperly constructed and maintained, or combined systems. Design and location specifications can prevent much of the damage to these systems.

Subdivision Regulations

Subdivision regulations guide the process by which large parcels of land are divided into smaller developable plots. They also control improvements such as roads, sewers, water and recreation areas. By requiring drainage, prohibiting encroachment on floodplains, requiring elevation of structures and locating streets and utilities in low risk areas damages can be minimized.

Tax Adjustments

State and local taxes can be used to discourage inappropriate uses of the floodplain and to encourage desirable uses. Lower taxes on lower density development and property or income tax relief for those suffering flood losses are two examples of how taxes could be used to moderate the impacts of floods.

Urban Storm Drainage

Urban storm drainage systems must be adequately designed, constructed and maintained to allow storm waters to drain from impermeable surfaces. Designing systems with room to grow to accommodate future development and increases in future storm flows can effectively reduce flood damages. Storm water detention and infiltration opportunities may also be provided as part of the system.

Zoning Codes

Zoning divides an area into specified areas for the purpose of regulating: (1) the type and use of structures and land, (2) the height and bulk of structures and (3) the size of lots and density of use. Floodplain zoning ordinances are an important part of the NFIP. Floodways are designated so that any development permitted in the remainder of the floodplain will not result in a stage increase beyond a prescribed amount of a given frequency flood at a specific location.

6.3 Estimating Benefits of Floodplain Evacuation

Background

With a growing interest in the natural functions and values of flood plains and riverine ecosystems as a means of reducing flood risks and flood damages, there is a growing interest in floodplain evacuation measures. Experience within the Corps, however, has indicated that floodplain evacuation is rarely economically efficient because it is necessary to account for the loss of the services provided by the structures (capital assets) that are removed. Furthermore, evacuation measures have been burdened with some of the more confounding, tedious and confusing procedures with which federal water agencies have to deal. This section describes current guidance and its implementation.

Current Guidance

Paragraph 2.4.14(a) of the P&G provides the basis for current economic evaluation of evacuation alternatives. It says, in part:

> *To the extent that Step 5 indicates a difference in land use for an evacuation plan, the benefit is the reduction in externalized costs of floodplain occupancy that are typically borne by taxpayers or firms providing services to floodplain activities ...Reduction of costs not borne by the floodplain activities may be a major benefit of projects to evacuate or relocate floodplain activities. Reduction of flood damages borne by floodplain activities should not be claimed as a benefit of evacuation or relocation because they are already accounted for in the fair market value of floodplain activities.*

This guidance has been a constant source of conceptual/theoretical confusion to non-economists and a constant source of measurement problems for economists.

The Rationale

The evaluation of most flood damage reduction measures is accomplished by comparing its costs to its benefits. For floodplain evacuation, the estimation of costs and benefits can result in the double-counting of benefits if care is not taken. This unique potential for double-counting has resulted in the development of benefit estimation procedures that can become laborious. The current procedure and its implications are discussed in the following paragraphs.

Capital Asset Pricing

A capital asset is a durable good that has the ability to generate a stream of income over time. Economic theory suggests that the value or market price of such an asset is the accumulated present worth of the stream of net income generated by the asset. A house is a capital asset. If rented, it can generate a stream of gross income. The net income stream is obtained by subtracting the expenses associated with owning and using the asset from the gross income.

Item	Amount
Annual Gross Income	$12,000
Annual Expenses	$8,000
Annual Net Income	$4,000
Capitalization Rate	10%
Asset Value	$40,000

Table 4 : Capital Asset Pricing

Table 4 shows a sample computation for a hypothetical house. Suppose the house can be rented for $1,000 per month ($12,000 per year). Further, assume that principle, interest, taxes, homeowner's insurance and maintenance sum to $8,000 per year. The net income is $4,000. To convert a perpetual annual stream of income to an accumulated present worth, i.e., to capitalize the $4,000, divide the annual net income by the interest rate. Here, we assume the interest rate to be 10 percent. The house, in our example, is valued at $40,000. Valuing assets with a shorter life span is slightly more complex.

The Problem: Structure Values in the Floodplain

Land and structures are capital assets. Houses can generate a stream of rental income; business structures generate a stream of income through sales. From these income streams we subtract the expenses associated with owning the asset to determine the net income and, subsequently, the property value. Flood plains add an additional expense to owning an asset.

Item	No Flooding	With Flooding
Annual Gross Income	$12,000	$12,000
Annual Expenses	$8,000	$8,000
Expected Annual Damages	$0	$2,000
Annual Net Income	$4,000	$2,000
Capitalization Rate	10%	10%
Asset Value	$40,000	$20,000

Table 5: Structure Values in the Floodplain

Flood damages are a cost of owning an asset in the floodpl**ain**. Assume expected annual damages are a reasonable estimate of the *extra* costs of owning a floodplain structure.

Considering the same house from the example above, in the floodplain this time, we see in Table 5 above that its market value is $20,000 compared to $40,000. This is because the floodplain house only *earns* $2,000 per year compared to the $4,000 earned by the flood free house. An asset that pays $2,000 per year is worth less than one that pays $4,000 per year and the different earning power is reflected in the price of the house.

To cut to the bottom line, suppose this floodplain house is to be purchased and razed. What price will be paid for it? If the house costs $20,000 then this value already reflects the impact of the average annual damages. A $40,000 house was purchased for only $20,000. This *reduction* exists because the capitalized cost of the $2,000 in expected annual damages has a value of $20,000. Thus, the cost of purchasing the home as part of a project implementation already accounts for the flood damages. If the analyst adds the reduced EAD to the project benefits, this is double counting the benefits of razing the house. The $2,000 benefit was realized when the house was obtained for $20,000 less than it otherwise would have been worth. If the no-flood/pre-flood price of $40,000 is paid for the house then it would be legitimate to claim the inundation reduction benefit, in this simple example (using the pre-flood value is the basis of current guidance, as will be late explained).

The benefit-cost analysis for this structure has two parts: costs and benefits. We paid a lower cost for this structure because the flood damages diminish the structure's income producing capability. The $2,000 in damages has been accounted for when it was subtracted from the gross revenue stream reducing the purchase price. If we claim the reduction of damages on the benefit side as well, we would have counted this damage reduction twice. We count the damage first when we realize a lower purchase price of the property; second, when we claim it as a benefit. If the purchase price of the asset reflects the presence of internalized damages it is double counting to also count the elimination of those same damages as benefits. Reality is even more complicated than this, however, as the following will reveal.

Suppose the homeowner found a way to get someone else to pay some of the costs of flooding for him. That is, suppose the flood costs could be externalized, as was once the case with subsidized National Flood Insurance (Historical Context Audio). The additional $2,000 expense would no longer be borne by the homeowner, only half of it is in the example shown below (Table 6). Annual net income is $3,000 and the house would be worth $30,000. In this case, $1,000 of the flood damage expense is externalized and the earning potential of the flood-prone house increases by $1,000 a year. The purchase price of the house, therefore, reflects some, *but not all, of the flood damages.* (Notice the change in wording of the third item in the table below.)

Item	No Flooding	With Flooding	With Flood Insurance
Annual Gross Income	$12,000	$12,000	$12,000
Annual Expenses	$8,000	$8,000	$8,000
Owners Share of Expected Annual Damages	$0	$2,000	$1,000
Annual Net Income	$4,000	$2,000	$3,000
Capitalization Rate	10%	10%	10%
Asset Value	$40,000	$20,000	$30,000

Table 6: Structure Value in the Floodplain with Flood Insurance

Expected annual damages for the house are $2,000 and all of this will be eliminated by taking the house out of service. The $30,000 price of the house captures some, but not all, of this reduction. So the inundation benefits would include that portion of the expected annual damages reduced that have been externalized, i.e., the $1,000 in costs paid by the NFIP, but not counted elsewhere.

The real problem with estimating nonstructural benefits for evacuation and relocation is to figure out the extent to which the purchase price of a floodplain house reflects flood damages. Suppose, to make a point, a local government policy required the city to pay half of all flood damages. The owner knows he only has to pay $1,000 of the $2,000 flood damages. The purchase price of this house is $30,000. The price reduction from $40,000, the value of an identical flood free house, to $30,000 represents a $10,000 reduction in project costs. However, the $1,000 paid annually by the government is an expense that can be eliminated if we evacuate this house from the floodplain. Hence, it is appropriate to include the elimination of the externalized costs of flooding as a benefit.

There is no such local policy that pays half of all flood damages but there is the NFIP. Does the existence of the NFIP allow homeowners to externalize some of the costs of owning a floodplain house? The answer depends on the nature of the flood insurance program and the extent to which policies are currently subsidized by taxpayers.

If the insurance program is actuarially fair and the homeowner pays an annual premium that is, over the long run, equal to his annual flood damages then the $2,000 cost of flood insurance will simply become one of the expenses of owning the house and the price will reflect this additional expense. In this case, the purchase price of the house is $20,000 and the reduction of flood damages is fully realized in the lower purchase price of the house. If the homeowner does not pay the full cost of the insurance program and receives a subsidy then he is able to externalize some of the costs of flooding. Eliminating those externalized costs is a benefit to the national economy.

In any community with flood insurance, all structures built before the first flood insurance rate map (FIRM) was adopted received subsidized insurance rates. New construction built after the FIRM must pay actuarially fair rates. Thus, in any given community it is possible that some houses receive a subsidy while others do not. It has not been necessary to appropriate funds from the taxpayer subsidy since 1985 despite Hurricanes Hugo and Andrew, the Midwest floods of 1993, Tropical Storm Allison and other recent events.

6.4 Current Evacuation Benefit Estimation Practices

The analyst's challenge is to avoid double-counting the economic impacts of evacuation while calculating estimates of both benefits and costs. The policy on how best to do this has recently changed in order to respond to Section 219 if the WRDA of 1999. There may be some confusion on this policy point, until the new policy changes are widely propagated. When revised, ER 1105-2-100 will be the principle source for this information. Until then, please reference CECW-PD, 22 January 2001.

Evaluation Procedure for Nonstructural Flood Control Projects

Section 73 of the WRDA of 1974 requires consideration of nonstructural alternatives in flood damage reduction studies. Section 219 of the WRDA of 1999directs the Corps to calculate benefits for nonstructural flood damage reduction projects using methods similar to those used in calculating the benefits for structural projects, including similar treatment in calculating the benefits from losses avoided. Further, it states that in carrying out this directive, the Corps should avoid double counting benefits.

Previous Corps guidance directed the use of only the externalized portion of prevented flood damages in calculating benefits for evacuation projects. The guidance was based on the fact that the internalized portion of flood damages is reflected in the reduced market value of the properties used in the calculation of evacuation costs, the cost of buyout of the floodplain. The internalized portion of flood damages includes uninsured losses, flood insurance premiums and deductible as well as agent's fees. Typically, externalized flood damages were estimated by calculating total flood damages using standard depreciated replacement cost techniques as in structural flood control projects and then subtracting the internalized portion of flood damages. As previously mentioned, the subtraction of the internalized portion of flood damages was intended to remove double counting from the benefit-cost calculation. Pursuant to CECW-PD 22 January 2001, the following new procedures, which avoid double counting internalized costs, are to be used.

Implementing Section 219 (a) of WRDA of 1999

1. **Benefit Calculation.** Flood damage reduction benefits for evacuation projects will be calculated as the total flood damages reduced, including internal flood damages. No correction will be made to remove the internalized portion of flood damages in the benefit calculation.
2. **Flood-free Land Costs.** Economic analysis for the cost of evacuation alternatives shall use comparable flood-free land costs in the valuation of floodplain land, and not the actual real estate cost of acquiring the land and structure. Flood-free land cost is the cost of comparable land without the flood-risk (defined as outside the FIA-designated 100-year floodplain). For the purposes of this guidance, land costs are defined as the land and associated structures.
    a. Information developed by real estate personnel during the feasibility study should be used for this flood-free land calculation. As part of the Real Estate Plan, the cost (market value) to acquire the floodplain property is determined by a gross appraisal. Additionally, for residential properties under Public Law 91-646, the amount by which the market value of a replacement dwelling (non-floodplain property) exceeds the market value of the displacement dwelling (floodplain property) also is determined. This cost (the market value of the floodplain property, land and structures, plus any additional amount to equal the market value of a comparable replacement dwelling outside the floodplain) is the flood-free property cost. A comparable replacement residential property under Public Law 91-646 means a dwelling that is decent, safe and sanitary and one that is similar with respect to features, size and location. However, for purposes of this calculation, if the floodplain dwellings are not up to decent, safe and sanitary standards, the incremental cost to upgrade to a decent, safe and sanitary home is considered a betterment and must be subtracted from the flood-free cost. Also, where last resort housing is anticipated, the market value of a comparable home outside the floodplain should be used, without regard to whether the home is available for acquisition.

b. Comparable flood-free estimates for nonresidential properties are not developed for compliance with Public Law 91-646; however, this information will now be required and can be developed by comparing property characteristics with information available on a multiple listing service or similar service. Coordination and involvement of real estate personnel is essential in determining appropriate non-floodplain land values.
c. The determination of non-floodplain land values will be described and documented in all decision documents where evacuation plans are considered. Note that this adjustment in costs is intended for use in the economic evaluation only and should not otherwise affect the financial costs associated with evacuation of the floodplain.

Chapter 7: Land Use Changes

- Other Benefits
- Intensification Benefits
- Location Benefits
- Policy on Land Value Benefits

7.1 Other Benefits

Flood damage reduction measures can affect land use. Most land serves the same purpose in the with-project condition as it does in the without-project condition. In these cases, the benefits of flood damage reduction are measured as the reductions in expected annual damages. Some land uses, however, change as a result of flood protection. When the land use remains the same, inundation reduction benefits accrue to the land and its improvements; when land uses change, location or intensification benefits accrue to the land.

When land uses change they change in one of two ways. First, the fundamental usage may remain the same but the land may be used more intensively. For example, the crop rotation is changed on agricultural land or more valuable crops replace less valuable crops. Homeowners might begin to use once unusable basements. Businesses may reconfigure production processes to become more productive. These changes in land use may increase national net income. If they do, an intensification benefit will result.

Second, the fundamental land use may change; this can result in location or intensification benefits. Vacant land may be put to some usage. If these changes in land use result in an increase in national net income, location benefits result. On the other hand, residential land may become commercial or commercial land may become industrial. These changes in land use from one use to a higher use can result in location benefits. The attached PowerPoint file illustrates the three ways a project may produce benefits. Click here to view a PowerPoint file that illustrates the three ways that a project may produce benefits. (Note: the file requires you to view as slide show in order to view animations).

The key to intensification and location benefits is that the provision of flood control is the sole factor responsible for the change. In other words, there is a land use difference in the with-project condition that would not have occurred in the without-project condition. The main challenges to estimating intensification and location benefits are (1) avoid double-counting income changes that have been included among inundation reductions benefits, and (2) avoid counting regional transfers as additions to net income.

Any effort to quantify and include land use change benefits must carefully establish a clear cause and effect link between the project and the changed land use. The narrative accompanying the benefit estimation should carefully address the issues of double counting and regional transfers.

Changes in Net Income

Think of the nation's resources as a large pile of things with a given value. Economic activity takes these resources and produces goods and services, i.e., real things of value to people. A change in net income is basically an increase in the value of this pile of goods and services. There are two ways to effect such a change. One is that the pile of real things increases in size. The incremental value of this increase in goods and services must be net of the additional resources required to produce them. A second change can occur if it takes fewer resources to produce the same size (and value) pile of goods and services.

Any time a flood damage reduction project has either of these two effects, a NED benefit results. Consider the following example.

Floodplain Land and NED Benefits

Land is a factor of production. It is the one truly indispensable input because no matter what is produced, you always have to be somewhere to produce it. Land has value because of its properties and its location. Floodplain land, by virtue of its fertility, flatness and proximity to water transportation has historically been among the first land settled. Because our modern communities, towns and cities have grown up around these early settlements, floodplain land has acquired significant location advantages in many places, despite its higher risk of flooding.

The value of land is based on the income stream that it can produce into the future. A piece of land that produces net income of $1,000 annually would be worth $1,000/r, where *r* is the interest rate. To explore the relationship among net income, interest rates and land values see the attached Market Value of Land.

Consider a piece of floodplain land for sale with four possible uses: open-space, agriculture, residential and commercial. One bidder for the open-space is an environmentalist who would enjoy the view and the openness of the land, valuing this benefit at $500 annually. A farmer could produce crops that would net him $1,000 annually. A home developer could build and rent houses that would net her $2,000 annually. A commercial developer finds it infeasible to locate on this land because of the existing flood problem. Each of these uses increases the size of the nation's pile of goods and services. What will each person bid for the land?

In order to determine a fair price for the land, each of these people has to figure out what the future stream of income or benefits they will get from the land is worth today. This is done by capitalizing the annual value. Using an interest rate of 10% for simplicity, the maximum each would pay for the land is $5,000 by the environmentalist and $10,000 and $20,000 by the farmer and home developer, respectively. The commercial developer does not bid.

In such a market, we would expect the residential developer to buy the land for as much as $20,000. Because he can expect to make more money on this piece of land, he can afford to offer more for the land. Thus, in a competitive market, the scarce location and physical characteristics of the land are efficiently allocated and this land is worth $20,000.

To listen to an audio file regarding capitalization, click here.

Now that the land has been allocated for residential usage, let us take a closer look at how the value of this land is determined. Assume there will be apartments built on the land. The developer incurs substantial costs to build and manage the structures that she counts on for income. There are construction costs, finance charges on her loan, operation and maintenance, periodic replacement costs for the roof, furnaces and the like, a normal rate of return on her investment, and annual taxes, among other costs. Again, for simplicity, assume the total annual costs are $10,000 per year. Bearing in mind that this includes explicit and implicit costs, and total revenues generated by renting the apartments are $12,000. The net income is $2,000, the basis for the $20,000 market value of the land. Assume this as the existing condition in a hypothetical floodplain.

One of the expenses of owning these structures is taxes. Taxes are easily anticipated annual charges levied by the government against the property. One of the physical-environmental attributes of the land is that it is prone to flooding. This can be likened to a tax that nature levies on a random basis as payment for the land's proximity to water, its fertility, topography and other related factors.

Nature's flood tax can be expressed as an expected annual value that is comparable to any other annual expense of operation. Let the flood tax, i.e., the expected annual damages, for a structure be $1,000 annually, i.e., on average over a very long period of time, flood damages to the houses that must be paid by the landlord average $1,000 per year.

If a flood damage reduction project completely eliminates the flood damage, hence the flood tax, the land would become more valuable. For simplicity of the example, assume revenues are still $12,000 annually, while costs have now fallen from $10,000 to $9,000 per year as a result of the *repeal* of the flood tax. Net income is $3,000 instead of $2,000 and the maximum price the developer could pay for the land if it is protected is $30,000, which is the new market value of the now flood free land.

The inundation reduction benefits accruing to the project are $1,000 annually or $10,000 on a one-time basis. Notice this is exactly the difference in the market value of the land without and with flood protection. These benefits occur simply because physical damages to the houses are reduced by an expected $1,000 per year. Use of the land does not change at all, (the land's output stays the same). So, it simply becomes less costly to produce that same amount of residential housing. This is an inundation reduction benefit.

As a practical matter, these benefits are approximated by changes in expected annual damages as detailed in this manual. It is conceptually feasible to estimate flood damage reduction benefits as the resulting change in the market value of the land and its improvements. Beware, however, that estimating benefits via the change in EAD captures the approximate change in market value. So, estimating benefits via both methods will result in double counting benefits.

Intensification Benefits

Let us back up a little and use this situation to illustrate an intensification benefit. Imagine that the developer is unable to rent the below grade garden apartments in each building because of the flood problem. Suppose that by leaving these apartments vacant she avoids all flood damages. Let the foregone annual net revenues that could have been realized from renting these unused units, be $1,500 annually. This represents an implicit cost of the flood problem to the owner of the apartments. If a project eliminates the flood problem and the developer can rent the additional units, these net revenues will now be realized. Under this scenario, the land is still used for residential purposes, without the project. The land value rises from the $20,000 originally paid to $20,000 plus the capitalized increase in rental values of $15,000. The land is now worth $35,000. This is an intensification benefit of $15,000.

Location Benefits

Let us consider a third possibility. Imagine that undeveloped land in the newly protected project area rekindles the interest of the commercial developer. Now that the property is flood-free, it may be well-suited for use as a new regional shopping mall. The land may be capable of generating $10,000 per year in this new use. In its undeveloped state it currently generates no income. For the simplicity of the example, assume the land has no open use value associated with it. An offer of $100,000 would cause a reallocation of land resources from undeveloped to commercial uses. This change in land use would yield a location benefit of $100,000. If the land had some open space benefits associated with it, say benefits of $2,000 a year, then the location benefit would be $100,000 less the capitalized open space benefit of $20,000 yielding a location benefit of $80,000.

This example illustrates the basic nature of the land use benefits that could result from a project. A well-behaved real estate market could be used to estimate the resulting benefits. As a practical matter, it is difficult to isolate the effects of flooding on the market value of land and its improvements in a reliable way. Consequently, alternative means of measuring these benefits have been devised. This manual has presented the hydro-economic model as an alternative for estimating flood damage reduction benefits. The following pages present some alternatives for estimating intensification and location benefits.

7.2 Intensification Benefits

When the type of land use is the same without or with a project but the intensity of land use changes, an intensification benefit may accrue to the project. The change in intensity of usage must be directly and solely due to the project and it must result in an increase in the nation's net income. The previous section indicated that intensification benefits could theoretically be estimated by changes in the market value of land attributable to a project. Because of practical difficulties in isolating the effect of flood risk on land values intensification benefits when they are estimated, are based on other techniques that measure changes in net income. Section III in Appendix E of ER 1105-2-100 provides a detailed description of the use of farm budget analysis to estimate intensification benefits due to changes in crop rotation. Agricultural land can be used more intensively by adding a crop to the rotation or by substituting more valuable crops for less valuable crops. Farm budget analysis basically estimates the costs of producing varying yields of different crops for the purpose of identifying changes in the farmers' net income.

Nonagricultural intensification benefits can likewise be estimated using changes in net income. One of the more common types of intensification benefit occurs when a firm finds it possible to produce a given amount of output using fewer resources as a direct result of a project. An example would be a production line that is able to move engines and other water sensitive machinery from an elevated location to a ground location, decreasing the operation and maintenance costs on the equipment and extending its useful life. Many businesses may find it possible to make more complete or more efficient use of their lots and building when a flood risk is reduced. Some of these changes can be translated into changes in net income. Reduced costs of producing a given amount of output are sometimes called efficiency benefits by the Corps. Examples of changes in net income attributable to increased output must be net of any costs incurred in the production of that output. Intensification benefits are specific to a given firm at a certain location. Consequently, it can be difficult to obtain the data required to provide credible estimates of these benefits due to confidentiality concerns.

Example

A manufacturing firm located in the floodplain made no usage of its at-grade facilities in an office building. This area was once used for storing company records, which were now kept at a warehouse many miles from the plant. Once the flood damage reduction project was completed, the firm relocated their records to the floodplain site, and therefore saved the cost of the warehouse. A shortage of warehouse space in the county assured that the vacant space would find an alternative usage. The plant was now able to produce the same output at a reduced cost equal to the warehouse rental and handling of records between the two locations.

Now consider an intensification benefit which results from land already in use being put to a higher use. Imagine land that is used for low density residential purposes and becomes attractive as an industrial park with a project. Most analysts would estimate existing flood damages to the low-density residential property as part of the without-project condition. The with-project condition damages should remove the low-density residential damages and include damages for the industrial park. This can get confusing. Consequently, it is often easier to use the change in net income or the change in market value of land as a measure of the benefits, but then there is no flood reduction benefit for the residential property as this would double-count benefits. Consider the table below.

	Without-Project	With-Project
Gross Income	$25,000	$75,000
Expected Annual Damages	$1,000	$5,000
Other Costs	$23,000	$60,000
Net Income	$1,000	$10,000
Intensification Benefits	$0	$9,000

Table 7: Without- and With-Project Intensification Benefits

As the example in Table 7 on the left shows, annual net income has increased by $9,000 (the value of the intensification benefit). Notice that at a 10 percent interest rate the land value has risen from $10,000 ($1,000/0.1) to $100,000 ($10,000/0.1) for a one time accumulated present value intensification benefit of $90,000 or an annual change in net income of $9,000 using our simpler assumption of a perpetual stream of income.

Using expected annual damages in this example, we would have shown a cost (an increase from $1,000 to $5,000) when there was in fact a benefit to the national economy. Recall that the change in EAD is used to approximate the change in willingness to pay for the flood protection. When land use does not change it is convenient to use the reduction in damages as an estimate of WTP. When land use changes, both benefits and costs can change and that requires a more careful estimation of net effects.

Table 8 on the right provides a different example which features no damage to the new industrial park development. A comparison of EAD without and with the project shows a decrease of $1,000. Intensification benefits are $14,000. These two sum to $15,000 but they double count benefits.

	Without-Project	With-Project
Gross Income	$25,000	$75,000
Expected Annual Damages	$1,000	$0
Other Costs	$23,000	$60,000
Net Income	$1,000	$15,000
Intensification Benefits	$0	$14,000

Table 8: Intensification Benefits - no damage to the new Industrrial Park

If the $1,000 reduction in EAD is counted as a benefit then the net income of residential land is now $2,000 and the value of the annual intensification benefit would be $15,000 less $2,000 or $13,000. Add to this the $1,000 in reduced flood damages and you obtain the same $14,000 in intensification benefits.

The land value would rise from $10,000 to $20,000 in the without condition. When subtracted from the $150,000 with-project condition (capitalizing the net income streams) the one time accumulated present value of the benefit is $130,000 or $13,000 annually with our simplified discounting of a perpetual sum. Add this to the $1,000 in reduced EAD and benefits for the more intense land use still equal $14,000.

There is considerable flexibility in how the benefits are estimated as long as the calculation is carefully supported and double-counting is avoided.

7.3 Location Benefits

Location benefits may accrue when there is a change in land use from undeveloped to developed that is directly attributable to the project. This change may represent new economic activity or a transfer of economic activity from one location to another. In either case, the value of the benefit is the change in net income resulting from the land use changes. In the case of economic activity that is transferred from one location to a project induced new location, care must be taken to focus on the change in income net of all costs related to the transfer.

Location benefits have been most often estimated by using the change in the market value of land. This is simplest when the change in land use is a new economic activity. To use a net income calculation, one must estimate the net income of the original undeveloped use (the without-project condition) and the net income of the higher developed use (with-project condition). The change in net income is the with-condition net income minus without-condition net income. An example was provided in the introduction to this topic.

In the past, some plans protected large parcels of undeveloped land that was subsequently developed. In time this came to be considered a negative consequence of flood damage reduction projects and policy has changed to discourage this sort of outcome. Current policy (ER 1105-2-100 cp. 3-14) says that if an economic activity is added to the floodplain because of a plan the location benefit is the difference between aggregate net incomes in the economically affected area with and without the project. In general, location benefits are expected to accrue to vacant properties interspersed with existing development.

Location benefits can be claimed for vacant property that is not interspersed (those large parcels of undeveloped land noted above) but the computation methods are somewhat different. First, the analyst must establish that the development of this land was going to occur in the future with or without a project. Thus, development of this vacant land would be part of the without-project condition.

Given that the development was going to occur in any event, the location benefit attributable to the project is the value of the resources saved by the project. These may be reflected in changes in land value or in lower costs of developing the land. ER 1105-2-100 cp. 3-14 directs that these location benefits be based on savings in future flood proofing costs. The presumption being that landfill or other flood proofing costs would be obviated by the flood damage reduction project and the value of the resources saved by avoiding these modifications are a benefit.

In theory, these benefits would be reflected in the increased market value of the land. It is, therefore, common practice to estimate location benefits as the lesser of changed market values of land or savings in flood proofing costs. In general, there are no problems with double-counting expected annual damages with these benefits as EAD are rarely estimated for vacant land.

Table 9 to the right suggests that (flood proofing) savings occur in the with-project condition only. This lowers the development costs and consequently raises the net income the investment will yield. A competitive market would capture these floodproofing savings in the market price.

	Without-Project	With-Project
Flood Proofing Savings	$0	$100,000
Development Costs	$1,000,000	$900,000
Change in Land Value	$0	$100,000

Table 9: Flood Proofing Savings

Theoretically, the two measures would produce the same benefit. Real estate markets are not perfectly competitive and differences in estimates using these two methodologies can occur. In order to avoid overestimation of benefits it is required that analysts use the lesser estimate of these two calculations.

7.4 Policy on Land Value Benefits

Appendix E to ER 1105-2-100 Paragraph E.18.l has the following to say about land development policy.

Land Development

The following general policy principles apply to land development benefits at structural flood damage reduction projects.

1. Projects or separable increments producing primarily land development opportunities do not reduce actual flood damages. Federal participation in these projects will not be recommended.
2. The NED plan is formulated to protect existing development, but inclusion of vacant property interspersed with existing development is acceptable. The NED plan may also

provide for the protection of vacant property that is not interspersed with existing development, if it can be demonstrated that the vacant property would be developed without the project, and benefits are based on savings in future flood proofing costs or reduction in damages to future development, whichever is less.

3. If no project or separable project increment can be economically justified to protect existing development, interspersed vacant property and/or property that would be developed without the project, there is no interest in expanding the area of protection to achieve land development (location) benefits, even if net benefits are increased and economic justification can be achieved.
4. A special case can be considered where the cost of protecting existing development can be substantially reduced if some vacant property not interspersed with existing development is included in the protected area. Such cases will be considered on their individual merits. Compatibility with Executive Order 11988 must be demonstrated.

The Flood Damage Reduction Matrix is a very helpful tool used by the Corps to analyze and understand factors relating to nonstructural floodproofing measures. It serves as a useful compilation of many of the issues discussed in this chapter.

Chapter 8: Using This Information

8.1 Introduction

Preceding topics have described the language, concepts, policies, models and methods of flood damage benefit evaluation used by the Corps in considerable detail. The purpose of this chapter is to pull these ideas together in a simple way and to provide a basic check list of tasks required to evaluate NED flood damage reduction benefits.

8.2 Know the Flood History

The first and most important step in any estimate of flood damage reduction benefits is to have a clear understanding of the flood problem. It is essential to know the flood history of your study area. At a minimum this means knowing what areas have been flooded, when they were flooded and how often, how deep the water was in each event, and how extensive the damage for each flood was. As obvious as it may seem, make sure you understand the source(s) of the flood waters. Click here to listen to an example. Special problems with velocity, ice, debris, siltation, toxic materials in the watershed, and so on should be fully explored and documented. Flood problems may be exacerbated by urban drainage conditions and/or groundwater flooding; they may be complicated by combined flooding. Make an effort to establish or learn the extent of flood damages for each event.

Collect evidence from as many sources as possible. These should include:

- Documenting recent floods in the field
- Prior flood reports
- Talk to people who live and work in the floodplain
- Read old, related newspaper articles
- Look at flood damage reports
- Talk to elected officials, reporters, government planners, engineers and responders
- Talk to any corps employees who may have worked on prior investigations in the area

Make sure you know how the floodplain has changed since earlier floods. Click here to listen to an illustration of this point. Study the available evidence to piece together a good understanding of the flood problem. Be sure to understand if and how the problem has changed over time. Is it getting worse, if so why? Understand the flood problems in the watershed not just the floodplain in your study area. Know the context of the flood problems you are trying to solve. Be sure to have a thorough understanding of the flood problem and flood history before you begin any systematic collection of data, e.g., a damage survey.

8.3 Visit the Floodplain and Study Area

A site visit is absolutely essential to good benefit estimation. There is some analysis that can be done in the office, but best practice flood damage reduction planning cannot be done from an office. You must see, walk, know and understand the floodplain in order to do good planning. Ideally the entire study team will take the opportunity to visit the study area together. Hydrologists, economists, environmentalists, archaeologists and others all see different things when they look at the floodplain. It is important for each member of the team to understand what others see. Familiarity with the floodplain, its features and use, and the development in it is indispensable to good economic analysis and planning. It is important for the sake of both accuracy and credibility to be able to discuss the details of the flooded areas in a knowledgeable fashion with the people who live and work there. There is no substitute for firsthand knowledge of the floodplain.

The team should know the orientation of the study area, see what was flooded, and understand the impact of floods on the lives and commerce of the affected community. Learn place names, major streets and other local landmarks. Be aware of major employers, industries and damage centers. Typically, one will see more by walking the area than by driving through it, so walk the area whenever it is feasible to do so. If you cannot walk the entire floodplain arrange to at least walk through the large damage centers. Seek out residents and business people who are knowledgeable about the area and the flood problem. Spend some time with them and use them as resources throughout the study.

8.4 Acquire Maps and Photography

To collect the necessary damage data you are going to need good topographic data. Ideally you will want maps that cover the entire area. Make a point to acquire good topographic maps and the available aerial photography. Get the best maps available. Visit planning commissions, county engineers, real estate developers or anyone else who may have developed maps. Inquire about the availability of GIS databases from government agencies, local universities and colleges. Economists would ideally like recent topographic maps with 2-foot contours and 100 percent identification of all improvements in the floodplain. Maps that delineate the entire floodplain plus a few more feet vertically are going to be most useful to you.

Be sure to coordinate your needs for mapping with other members of the study team. Ask what mapping is going to be prepared for the study and make sure your needs are met by any contracts to survey or develop maps. Economists will need good elevation data for their damage survey so make this a priority. If good mapping is not forthcoming consider having a survey team mark elevations for you throughout the floodplain where you will be conducting damage surveys (Click here to listen to a related audio file). Topographic mapping may be supplemented by information from sewer system inverts, road and highway maps, property plats and the like. Always begin your search for mapping and photography with local sources and surveyors' offices. The county engineer's office is a good place to begin.

Technology continues to produce new options for estimating elevation data remotely. LiDAR is just one example of this. There are a number of software packages and algorithms available for producing elevation data estimates based on a variety of data inputs. Quad sheets are maps prepared by the U.S. Geological Survey that cover 7.5 minutes of longitude and latitude. They rarely have the kind of topographic information required for a quality damage survey, but they are available for all of the U.S. and they can sometimes be useful.

8.5 Know Land Use Plans

Best planning practice requires you to become intimately familiar with land use plans for the both the floodplain and its drainage area. You need to know how the land is used in order to estimate existing damages. You will also need to know how this land use may change in the future if nothing is done about the flood problem in order to project the future without-project condition and the flood damages that will accompany it. Likewise, it is important to be able to provide a reasonable and well-supported description of the changes in land use that will result from a specific plan, i.e., one or more with-project conditions. Specific knowledge of the floodplain and watershed land uses may also be important for the estimation of location and intensification benefits.

A good analysis will identify the allocation of floodplain land to the relevant land use categories for existing and future without- and with-project conditions. These are usually the categories discussed earlier in this manual. Knowledge of floodplain land usage should be detailed and specific. Land use changes in the floodplain will affect flood damages through increases in the damage base. Some land use changes could also affect hydrology and hydraulics. Consequently, it is equally important to be aware of land use changes for the watershed not just your floodplain. In general this knowledge will not be as detailed for watersheds where land use changes are expected to have no effects on runoff or stream flows. Where changes in land use can affect runoff and the frequency of flooding it is important to have good evidence to support the expected changes.

Population growth is usually the driving force for most land uses changes. Consequently, it is typically necessary to obtain the best available population forecasts to estimate the speed with which the study area may develop. This development can have important implications for the discharge-frequency or depth-damage relationships. Analysts should be able to satisfy themselves and others that the relationships between population growth and land use change are reasonable.

It is important to find out if there are any specific plans for urban renewal, new developments, industrial parks and the like. You are basically looking for planned changes that could change either the damage base or the frequency curve. This information may be obtained by visiting planning agencies, redevelopment corporations, economic development agencies, chambers of commerce and the like in the watershed. If there is a master plan for the area or any part of it become familiar with it.

A forecast of land use changes can be prepared by the study analyst or they may simply adapt a study done by local interests. It is vital that all study team members be working from the same set of land use projections as this is a critical component of the without project condition forecast. The hydrology, economics and environmental studies must all agree. This necessitates that the study team coordinate closely and carefully in preparing its land use forecasts.

8.6 Coordinate with Others

Talk to people. Talk to them early in the investigation and talk to them often. Communicate with the members of your study team, the local partner's team, floodplain residents and business people.

Flood damage benefit estimation requires forecasts. There will be forecasts of future land use, future hydrology, perhaps even future hydraulics and other variables. These and other specific forecasts will be used to construct a most likely without-project condition that must be the same for everyone involved in the investigation. The economic, environmental, hydrologic and hydraulic, social and all other effects estimated in an investigation must be based on a common and consistent set of forecasts. The only way to assure that consistency is through early and frequent coordination throughout the investigation.

The project economist should coordinate his or her analysis with other Corps and nonfederal partner analysts. The coordination begins by identifying the data that will be needed to complete the economic studies. This includes such things as identifying damage reaches and getting the hydrology and hydraulic data you'll need for your analysis. In some cases this will include inputs for the HEC-FDA program, in others it might be rating and frequency curves for specific cross-sections of a stream reach. Generally, such information will be needed for without-and with-project conditions. If topographic data are going to be needed, this must also be coordinated with the mapping needs of other study participants. Using property values for benefit estimates may require the support of real estate personnel or surveyors. In best practice the coordination also includes providing others with the data they will need for their analyses. H&H analysts, for example, will often need information from the economist on future land use in the floodplain and the drainage basin.

Corps economists must coordinate their study efforts with other study team members early and often. You have two basic goals in coordinating with other team members. One is to assure that your data needs are met by the team's data collection efforts and that their needs are met by your data collection efforts. The other goal is to assure that everyone is working from a clear and consistent set of assumptions. Thus, it is essential to communicate with Hydrology and Hydraulics (H&H), Real Estate, Surveys, Environmental and perhaps other Corps offices and their counterparts with the nonfederal partner. If the opportunity to contact these parties is not provided for you, take the initiative on your own. Do not wait for others to come to you and ask you what you need. Be proactive and tell them. Find out who is on the team and get to know them and their responsibilities for the investigation. Talk about their work and yours. Ask them if they need anything from you; tell them what you need from them. Make sure they know specifically what you need from them and when you need it in order to do your analysis. If contractors are acquired to accomplish some or all of this work, be sure to ensure that they coordinate as closely as you would.

8.7 Identify the Floodplain

Put in the simplest terms: as a Corps economist involved in flood risk management, you need to know what gets wet, how often and how wet. That means you must know the location of the floodplain. It is essential information for data collection and analysis. With the help of your hydrology and hydraulics experts delineate the limits of several flood plains on the map(s) you will use for data collection and analysis. One of these delineations should be the flood of record, another might be the standard project flood plus a few vertical feet to provide an upper bound on the property exposed to the flood hazard. You will have to decide how much property at risk of flooding will be included in your damage survey. Unless you know the analysis will be restricted to the consideration of more frequent flood events it is common practice to survey the area that would be inundated by a rare event, such as a flood with an annual exceedance frequency of 0.2 percent or less plus 1 or 2 feet. As a practical matter the floodplain is often rounded off to the next highest 5 foot contour. Thus, if your reference floodplain reaches 492.3 feet in a reach you might survey property within the 495-foot contour.

Once the floodplain has been carefully delineated you will need to identify damage reaches. This is less important than it once was if you use the HEC-FDA program; regardless, it is still important for plan formulation. You will need to be able to break out your damages in such a way as to be able to consider the incremental justification of various plan components. This means anticipating configurations of damage reaches that will best serve the team's plan formulation needs.

Each potential flood damage reduction measure will reduce damages in some part of the floodplain. You should be able to estimate the damages in the area affected by each plan component. In order to do that, you will need to define reaches at a small enough scale to be able to aggregate damages for the smallest impact areas of your likely flood damage reduction measures.

This idea is illustrated with two extreme examples. If you plan to use nonstructural measures on a structure-by-structure basis then each structure is essentially a damage reach! If you consider a ring levee around a small town then the entire town may constitute a single reach. Once reach designations were dictated by hydraulic and hydrologic features in tandem with economic damage centers. With HEC-FDA it is possible to designate reaches for the convenience of plan formulation.

8.8 Plan Your Damage Survey

The purpose of a damage survey is to collect all the information necessary to estimate the inundation reduction benefits of your alternative plans. The very first thing that needs to be done is to define the objective(s) of your survey. Most often it will be to collect the data necessary to generate the stage-damage curves needed to estimate expected annual damages for your floodplain under a variety of forecasts.

The next task is to ascertain the extent of your damage survey. You neither want to collect data you will not use nor to miss data you need. Carefully decide the spatial extent of your damage survey.

Next, decide whether you will conduct a census of all floodplain development or a sample of some of the development. A census has the advantage of being inclusive and descriptive of all floodplain development. It is more time-consuming and expensive than a sample. A sample is faster and less costly. It can also be more accurate in some instances. Faced with the task of conducting surveys on thousands (census) vs. hundreds (sample) of houses, it may be possible to do a more accurate and thorough job on fewer houses, producing a more accurate estimate of damages over all.

For example, if you have 1,000 hours to devote to a damage survey in a floodplain of 20,000 structures it would be very difficult to get quality data on each structure. It may, however, be reasonable to do a thorough job on 1,000 structures. If you decide to take a sample, you will want to use some sort of random sampling technique. A few links are provided below to introduce ideas related to planning a sample.

- Elementary Survey Sampling - this is an excellent textbook for analysts not familiar with sampling techniques and issues.

- [How to Plan a Survey]
- [Random Samples]
- [Sampling]
- [Random Sampling]

Will you collect your data onsite or remotely? Most damage surveys are conducted onsite in door-to-door survey efforts. The growth of GIS databases increases the potential for collecting or generating the required data through more remote sensing techniques.

Once you have determined your basic approach to collecting data you will need to identify the specific data variables you will need to collect and the instrument(s) of their collection. This could be a simple survey form or questionnaire or entry directly into an electronic database.

There are a great many methods for collecting damage data. Standardized damage curves may be used or site specific damage estimates can be prepared in an interview process. The "how to plan a survey" sites linked above detail many of the resources that will be required and the associated costs incurred in a survey. They are worth reviewing for that information.

You will need to know the kinds of equipment needed for your survey. For example, maps and an ample supply of forms, pens and clipboards, and cameras (if desired) will be needed. Hand levels may be needed for collecting elevation data for the structures.

It will be important to know how many people will be available for the survey and the timeframe over which the data will be collected. It is important to plan the sequence of data collection. Which areas will be surveyed in which order? If interviews will be required it may be necessary to schedule them in advance of their conduct.

Sample Survey Design Checklist:

- ☐ Prepare a statement of survey objectives
- ☐ Define the population to be sampled
- ☐ Identify and obtain the frame
- ☐ Choose a method of measurement
- ☐ Specify the measurements and the instrument for obtaining them
- ☐ Select and train field workers
- ☐ Pretest your survey instrument and field methods
- ☐ Organize your field work in detail
- ☐ Organize the handling of information throughout the survey
- ☐ Identify the analyses to be completed

Survey Design

Statement of Objectives of the Survey

State the objectives of the sample survey clearly and concisely. Refer to your objectives throughout the design and execution of your survey. This statement should identify the population parameters you are interested in measuring (ground floor elevation, style of house, depreciated replacement values and so on) and the uses to which they will be put. Keep the objectives simple so everyone working on the survey can understand them. This is the best way to avoid designing a sample that is at odds with the objectives of the survey. A sample objective could be: "To estimate the content-to-structure ratio of residential properties for use in the estimation of expected annual flood damages."

Target Population to be Sampled

Carefully define the population to be sampled. For example, the population may be defined as "all residential properties wholly or partially located within the standard project floodplain of the Dandelion River in Knightsbridge." Defining the population may present no problem. On the other hand, rules may have to be established to guide the definition. For example, is a building with a first floor used as a storefront and a second floor apartment, residential or commercial? Care must be taken in carefully defining the population, so that sample selection is possible.

The definition must enable analysts to clearly identify what does and does not belong to the population.

Frame

The population to be sampled **(sampled population**) should coincide with the population about which we want information (**target population**). Select the frame (or frames) so that the sampled population and the target population show the closest agreement possible without double counting. For example, we do not want to draw a sample from the entire county of Stepney if we are interested only in the floodplain of Knightsbridge.

Sources of Frames

A frame is essentially some sort of listing of all the items that belong to your target population. Therefore, it includes all the items you might want to select in your sample. For election surveys it would be a list of every voter. For a flood damage survey it would be a list of every floodplain property.

Frames come from many places. Some are good, others are not so good. Telephone directories are not good frames for reaching households. Clearly, a household without a phone is excluded, but, worse, all unlisted phone numbers are excluded as would be cell phone numbers. Thus, telephone samples rely on random-digit dialing devices.

Maps provide good sampling frames for many water resources planning purposes. Inasmuch as many planning information needs are spatially-based, a good map can always be used as a frame if the sampling units are defined as a non-overlapping and complete set of smaller plots of land.

There can be multiple sources of frames. Frames for flood damages surveys could be aerial photographs of the floodplain, topographic mapping, quad sheets if area based sampling is to be used, Stewart's Crisscross Directory or other similar indices listing property addresses. Tax roles and property maps could also be used. A drive-by videotaping of all properties in a relatively small floodplain might be possible. Telephone directories (if there are no unlisted numbers), census maps and reports and computerized databases are additional sources of frames. Frames can sometimes be purchased from direct mailing or other marketing services. In short, there are often more potential frames than one might first imagine. Identifying the best one simply requires some perseverance.

Sample Design

Choose a sample design that allows for the attainment of enough information to meet the objectives of the survey. Sample design includes such things as whether you will do a probability sample or a quota sample, as well as the size of the sample. If a probability sample is chosen, sample design also includes deciding whether it will be a simple random sample, a stratified sample, a cluster sample or so on. If the sample is not carefully designed the survey may not yield useful information. These issues are discussed in the links provided above.

Method of Measurement

Choose a method of measurement. The most commonly used measurement methods include: personal interviews, telephone interviews, mailed or other self-administered questionnaires, and direct observation.

Measurement Instrument

Specify the measurements that are to be obtained from the sample and how to take them. As the survey instrument is prepared it is important to make sure that all the data being collected are relevant to the investigation and that no essential data are omitted. There is a tendency to ask too many questions of human populations. As a general rule of thumb, it is better to do less and do it better. Long surveys can lower the quality of the response. All survey instruments should be designed so they minimize non-response and incorrect response bias.

No matter what information is collected in a sample, it is going to be necessary to record it. Samples of human populations generally require some sort of questionnaire. Direct observation of other populations will require a log or other standardized format for recording the facts of interest in the analysis. These are examples of survey instruments.

Selection and Training of Field-Workers

Someone must collect the data. Field workers must be carefully selected and taught what measurements to take and how to take them. Training should include the purpose and importance of the survey. Care must be taken in instructing field workers in the use of data gathering equipment. Workers dealing with human populations must be carefully trained because response rates and the accuracy of responses are affected by the interviewer's personal style, appearance, tone of voice, body language and other similar factors.

Pretest

Test your survey instrument and field methods on a small scale before you begin your data collection in earnest. The pretest is crucial because it enables you to field-test questions, try out equipment, observe field workers, experiment with data management and surface problems before they become critical.

Suppose a structure selected for the survey from an aerial photograph has burned down, what does the surveyor do? What if a person refuses to cooperate or chases you from their building? Suppose you begin to interview a property owner and suddenly realize the wording of your questions is all wrong for these people? These are issues that need to be resolved before a survey begins. The pretest can be expected to result in modifications to your survey design before full-scale sampling is begun.

Organization of Field Work

Plan your field work in detail. Perhaps you have ridden an amusement park ride that played the looped message, "You will get wet on this ride." A similarly looped repeating message, "Problems will arise with your sample survey," should be developed for all those involved with it. There will be people collecting data, coordinators and data managers. The various jobs have to be carefully organized with clearly delineated lines of responsibility and authority. Field workers must be carefully supervised in the field and the quality of their work should be regularly reviewed. Review of early results is particularly important. Someone should be available to answer questions that arise. The details of who goes where, when, and for what purpose are critically important to a good sample survey design.

Organization of Data Management

Outline how each piece of information is going to be handled throughout the survey. For example, first it is measured and recorded by a field worker. Then it is reviewed by a coordinator, who gives all complete and acceptable surveys to the survey's data manager. Incomplete surveys are returned to the field worker for completion or to a coordinator if the worker is not capable of completing the work. The data manager sees that the survey responses are entered into a data file and that the data file is complete. Encoded survey forms are stamped or marked complete and returned to the senior investigator for storage. Data files are edited for accuracy and when complete are carefully backed-up.

A well-prepared data management plan is essential. Incomplete forms, lost data, multiple copies of data files with duplications and the like can plague any survey. A data management plan should provide for the processing and whereabouts of each datum from the time it is collected in the field to the time it is stored for future reference. These plans must include a plan for quality control.

Data Analysis

Identify and outline the analyses that are to be completed. This means the sample statistics need to be clearly identified. Accuracy, precision and cost trade-offs need to be anticipated and decided. The final use of data must be made explicit or you risk collecting data unsuitable to your decision making process.

8.9 Generate Damage Survey

The results of your data collection efforts must be analyzed and aggregated to produce stage-damage curves for each of your designated damage reaches. This task is usually automated by the software used for the analysis. Stage-damage curves are, for example, normal outputs of the HEC-FDA program. Traditionally, separate damage curves have been generated for structure, their contents and other types of damage. You have the freedom to designate the categories of damage curves most relevant to your analysis, subject only to the constraint of the reporting requirements of your software.

8.10 Estimate Without-Project Expected Annual Damages

The most significant calculation you will produce is expected annual damages for the floodplain under the without-project condition. This estimate, discussed at length earlier, is the baseline against which all other plan effects will be measured. HEC-FDA is the most common tool used for estimating expected annual damages by the Corps today.

It is often useful to divide total expected annual damages by the number of structures in the floodplain to get an average EAD per structure. Some analysts use this approach for the different types of damages: residential, commercial, industrial, public and other. The average damage per structure provides a crude *sanity check* on the EAD estimates. A high mean EAD value warrants some careful scrutiny as it basically reflects the *tax* imposed by nature of floodplain residents. It needs to be a reasonable and supportable magnitude. The analyst should be able to support the average level of EAD with information gained during the flood history investigation.

8.11 Understand How Plans Work

You will need to know how each measure in each plan works to reduce floods in the future. Then you must, with the help of the H&H analysts, be able to model these effects by altering one or more of the hydro-economic model inputs. This must be done on a reach-by-reach basis to reflect the plan's effects. It is possible that reaches will be defined in different ways for different plans. (Click here to review EAD and the with-project condition.)

8.12 Estimate With-Project Expected Annual Damages

A separate expected annual damage estimate is prepared for each alternative plan under consideration by the planning team. This estimate, discussed at length earlier, is the improved condition. Subtract the with-project condition EAD from the without-project condition EAD to obtain an estimate of the flood damage reductions attributable to each plan. HEC-FDA will calculate these values as well as the without-project condition EAD.

8.13 Check Your Work

Estimating the expected annual damages of a floodplain is sophisticated analytical work. It requires a great deal of complex and technical information. It can be very easy to make mistakes during the analysis.

Data errors are one obvious source of mistakes. Error checking or data verification procedures are an important part of a total quality management approach to flood damage reduction analysis.

Human errors are perhaps the most common sort of mistakes made. Review your work for *simple* mistakes such as using damages for Reach 1 with the frequency curve for Reach 2, using out of date data files, and the other similar errors. After you have reviewed your own work, have someone review it for you prior to the independent technical review (ITR). We are all prone to the inability to see the mistakes we have made.

8.14 Expect Revisions

Planning is an iterative process. Nothing is ever final until the project is built. Sometimes even then it is not final.

Expect to have to make revisions to your analysis. Sometimes the revisions are substantial, even after you think your work is finalized. Incorporating a new high-water mark may change the H&H inputs to your model. Floodplain development changes all the time, you will be challenged at times to determine what changes are significant. The review process will usually result in changes that will necessitate a new estimate for expected annual damages.

As a project languishes in the review and political processes, some inputs may become dated. Conditions change. New information arrives. Errors are found in old information. As a result, expect to have to update your analysis several times. Document your work carefully and take care to preserve access to key study materials like maps, damage survey documents, interview summaries, worksheets, computer outputs and the like. Back-up all databases and files related to your work.

8.15 Forecast Land Use Changes

Some flood damage reduction plans will have no effect at all on land use. Others may have substantial effects on land use resulting in location or intensification benefits. It is important to forecast any changes in land use attributable to a plan. There should be a separate forecast for each plan.

There is a temptation, once the without-project condition has been forecast to use the same stage-damage curve for each with-project condition. You should carefully consider how land use might change as a direct result of each alternative plan considered. The with-project condition stage-damage curves should be revised as necessary.

Forecasted changes in land use need to be supported with evidence. It is not sufficient to present the fondest wish of the local Mayor as support for a changed future land use condition. Forecasts need to be supported by interviews, projections, plans and market details.

Take care to explain why a forecasted change is considered a project induced effect. Does the project change the timing or nature of land use? Why and in what way? Explain in a clear and simple narrative.

In this task you are looking for substantial changes that will result in changes in the net income accruing to the land. If you find evidence to support these changes, calculating location or intensification benefits may be appropriate.

8.16 Calculate Changes in Net Income

If you have identified changes in land use that can be directly attributed to a particular plan and supported with direct evidence, the next step is to calculate the changes in net income accruing to that land. The techniques used to do this are those described in the discussion of location and intensification benefits.

8.17 Document Your Work

Take the time to document your analysis as you go. This documentation includes the obvious narratives that will be required in any reports generated by the study team. It also includes the memorandums to the file that are required to help you or the analyst who will succeed you to understand in a very precise way just what you did do during your analysis.

In the immediate aftermath of a competed analysis it is easy to convince yourself that you will never forget the details of this analysis. But soon enough you will be immersed in your next assignment and the detailed memories will quickly fade.

Document your work for the files as if a new person is going to have to redo your work in two years time. Not sure what that entails? Just imagine yourself as that new person cracking open a file drawer and a CD-ROM or flash drive. What do you hope to find there? What kinds of explanations will you need to be able to effectively and efficiently use these materials? Pictures and video can be especially useful means of documenting study details. If you do not have the time to document what you did, take the time to make an audio or video file explaining what you did. It takes less time and is often more useful.

Documenting your analysis means gathering and organizing all the information you collected. Provide annotations to explain the significance and use of materials that may not be obvious to others. Take the time to write or record a memorandum for the file (MFF) that explains any issues that arose and how you resolved them. Jot down notes on the limits of the reaches and why you defined them as you did. Keep files and a back-up of all your data files. Write or record an MFF that explains what each data file holds and how it was used.

No one has time for this. Make the time. The time you take to document your analytical process will save uncountable hours if the analysis is ever revised. And what analysis is not revised?

Glossary

AEP	Annual exceedance probability
CBD	Central Business District
CCI	Commercial Content Inventory Program
CDF	Cumulative distribution function
CE7	Commercial Estimator Program
CFR	Code of Federal Regulations
cfs	Cubic feet per second
CNP	Conditional Annual Non-exceedance Probability
EAD	Expected annual damages
EC	Engineering Circular
EGM	Economic Guidance Memorandum
EO	Executive Order
ER	Engineering Regulation
FDA	Hydrologic Engineering Canter's Flood Damage Analysis
FEMA	Federal Emergency Management Agency
FIA	Flood Insurance Administration
FIRM	Flood insurance rate map
FOR	Flood of Record
HEC	Hydrologic engineering center
HEC-FDA	Hydrologic Engineering Center's Flood Damage Analysis computer
IWR	Institute for Water Resources
LiDAR	Light Detection and Ranging
MSA	Metropolitan statistical area

NED	National Economic Development
NFIP	National Flood Insurance Program
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic Atmospheric Administration
NRCS	Natural Resources Conservation Service
OBERS	Office of Business Economics Research Service
P&G	Principles and Guidelines
P.L.	Public Law
RE7	Residential Estimator Program
SPF	Standard Project Flood
STOL	Stage that corresponds to the top of the new levees
WRDA	Water Resources Development Act

U.S. Army Engineer Institute for Water Resources

The Institute for Water Resources (IWR) is a U.S. Army Corps of Engineers (USACE) Field Operating Activity located within the Washington DC National Capital Region (NCR), in Alexandria, Virginia and with satellite centers in New Orleans, LA; Davis, CA; Denver, CO; and Pittsburg, PA. IWR was created in 1969 to analyze and anticipate changing water resources management conditions, and to develop planning methods and analytical tools to address economic, social, institutional, and environmental needs in water resources planning and policy. Since its inception, IWR has been a leader in the development of strategies and tools for planning and executing the USACE water resources planning and water management programs.

IWR strives to improve the performance of the USACE water resources program by examining water resources problems and offering practical solutions through a wide variety of technology transfer mechanisms. In addition to hosting and leading USACE participation in national forums, these include the production of white papers, reports, workshops, training courses, guidance and manuals of practice; the development of new planning, socio-economic, and risk-based decision-support methodologies, improved hydrologic engineering methods and software tools; and the management of national waterborne commerce statistics and other Civil Works information systems. IWR serves as the USACE expertise center for integrated water resources planning and management; hydrologic engineering; collaborative planning and environmental conflict resolution; and waterborne commerce data and marine transportation systems.

The Institute's Hydrologic Engineering Center (HEC), located in Davis, CA specializes in the development, documentation, training, and application of hydrologic engineering and hydrologic models. IWR's Navigation and Civil Works Decision Support Center (NDC) and its Waterborne Commerce Statistical Center (WCSC) in New Orleans, LA, is the Corps data collection organization for waterborne commerce, vessel characteristics, port facilities, dredging information, and information on navigation locks. IWR's Risk Management enter is a center of expertise whose mission is to manage and assess risks for dams and levee systems across USACE, to support dam and levee safety activities throughout USACE, and to develop policies, methods, tools, and systems to enhance those activities.

Other enterprise centers at the Institute's NCR office include the International Center for Integrated Water Resources Management (ICIWaRM), under the auspices of UNESCO, which is a distributed, intergovernmental center established in partnership with various Universities and non-Government organizations; and the Conflict Resolution and Public Participation Center of Expertise, which includes a focus on both the processes associated with conflict resolution and the integration of public participation techniques with decision support and technical modeling. The Institute plays a prominent role within a number of the USACE technical Communities of Practice (CoP), including the Economics CoP. The Corps Chief Economist is resident at the Institute, along with a critical mass of economists, sociologists and geographers specializing in water and natural resources investment decision support analysis and multi-criteria tradeoff techniques.

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