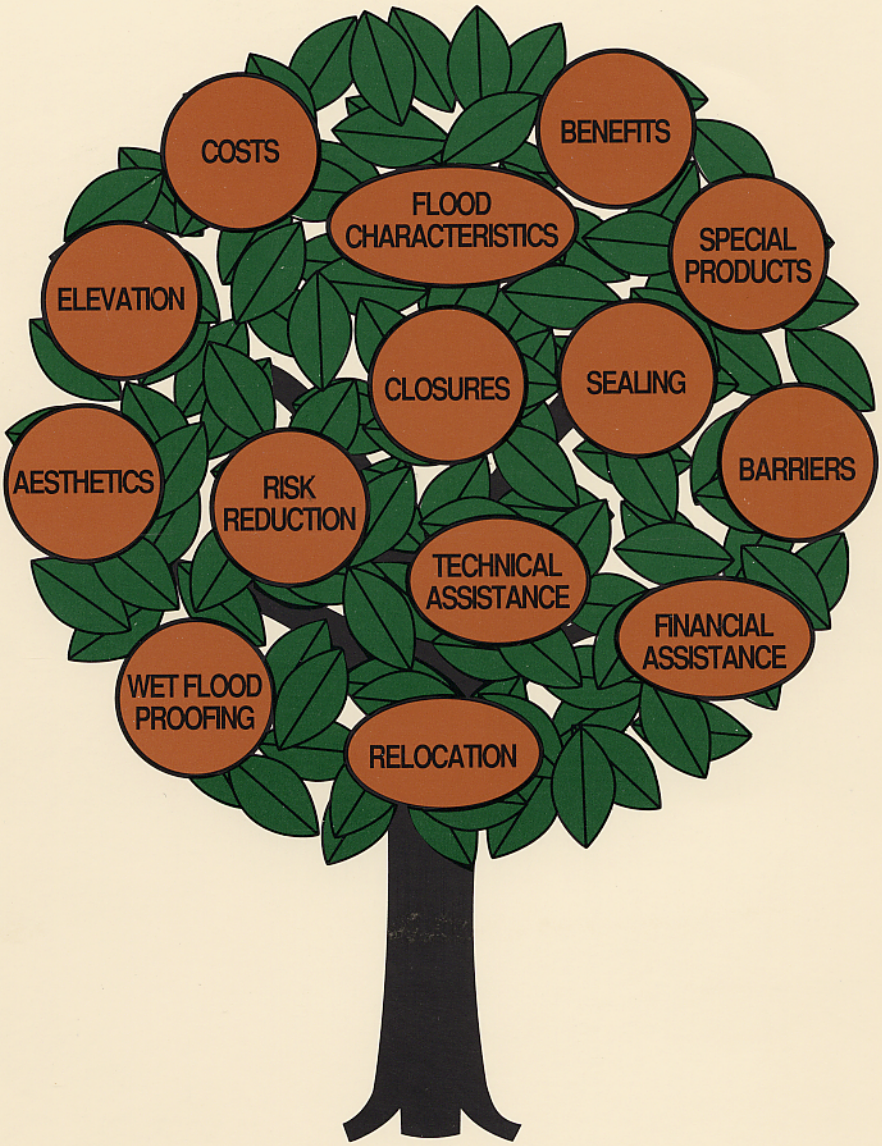
FLOOD PROOFING

How to Evaluate Your Options



Decision Tree

US Army Corps of Engineers
Flood Proofing
NATIONAL FLOOD PROOFING COMMITTEE

July 1993

PREFACE

FLOOD PROOFING – HOW TO EVALUATE YOUR OPTIONS

This document has been prepared to help answer the question, "Should flood proofing be used?" It is intended only as a tool to assist in making a preliminary evaluation of whether or not flood proofing is appropriate and what may be the best flood proofing measure to consider. Prior to implementing any flood proofing measure, the property owner should consult an experienced engineer or contractor in order to conduct final evaluation and design.

Chapter One discusses how flood proofing can reduce flood damage to buildings and their contents. The effectiveness and safety of flood proofing measures are also addressed, as well as the suitability of flood proofing for various building types.

Chapter Two addresses factors that should be considered when contemplating flood proofing, such as local building codes, high costs associated with some types of flood proofing, and the inability to flood proof certain types of buildings. Potential impediments are listed as factors to consider early in the process of evaluating flood proofing. Other factors may involve personal preference, such as architectural considerations, aesthetics, inconvenience, and concern for health and safety. The chapter also covers the availability of technical and financial assistance.

Chapter Three provides brief descriptions of various flood proofing measures and refers the reader to sources providing more detail on measures suitable for the structure being evaluated. General types of flood proofing included in this section are elevating the building, relocating the building, floodwalls and levees, dry flood proofing, and wet flood proofing.

Chapter Four assesses the characteristics of flood situations. These characteristics must be taken into consideration and may involve high velocity flow, rapid rate of water level rise, excessive water depth, wave action, and soil types that are permeable and/or erodible.

Chapter Five summarizes the thought process of evaluating physical, economic, and other factors involved in determining whether flood proofing is a viable option for a structure that has experienced flood damage or has a significant potential for being flooded.

Appendix A presents a detailed explanation of how to evaluate flood proofing options. It includes a description of how to compare the benefits of flood proofing with the costs of flood proofing using a detailed economic analysis. It also discusses other factors involved in making a detailed evaluation including assessment of the characteristics of the flooding, the building site, and the building itself and the applicability of specific flood proofing measures.

Appendix B contains worksheet forms and graphs.

Appendix C addresses hypothetical cases and illustrates a variety of different factors that influence decisions about whether or not to flood proof.

A/E	Architectural/Engineering
BFE	Base (100-year) Flood Elevations
cfs	cubic feet per second
COE	U.S. Army Corps of Engineers
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
fps	feet per second
HUD	Department of Housing and Urban Development
LOMA	Letter of Map Amendment
NFIP	National Flood Insurance Program
SBA	Small Business Administration
SCS	Soil Conservation Service
TVA	Tennessee Valley Authority
USGS	United States Geological Survey
NGVD	National Geodetic Vertical Datum

Alluvial Fan Flooding: Floods emanating from the confined channel of a mountain canyon (apex) and proceeding onto a relatively flat fan-shaped valley below. Active fans involve braided channels that occur erratically, creating random, unpredictable patterns.

Buoyancy Force: Buildings with basements located in pervious soils will experience uplift forces on the basement floor which are caused by water seeking to rise to the flood water level adjacent to the building. If the weight of building is less than the uplift forces, the building will float or the floor will collapse.

Flood Frequency: Average number of years between exceedances of specific flood magnitudes. Also referred to as annual exceedance probability (in percent) of a flood being exceeded in any given year.

Hydrostatic Force: Structural loading on buildings caused by still-water floods.

Hydrodynamic Force: Structural loading on buildings caused by moving floodwaters.

TABLE OF CONTENTS

FLOOD PROOFING – HOW TO EVALUATE YOUR OPTIONS

PREFACE ---------- *i*

ABBREVIATIONS AND ACRONYMS AND TERMS ---------- *ii*

CHAPTER ONE—**INTRODUCTION**
- Flood Damage Reduction ---------- 1
- Effectiveness ---------- 2
- Safety ---------- 2
- Building Types ---------- 2

CHAPTER TWO—**SHOULD FLOOD PROOFING BE USED? THINGS TO CONSIDER**
- Flood Proofing Assistance ---------- 3
- Building Codes ---------- 3
- Cost Estimates ---------- 3
- Secondary Benefits ---------- 4
- Inconvenience ---------- 4
- Health and Safety ---------- 5
- Architectural Aesthetics ---------- 5
- Emergency Measures ---------- 5
- Flood Insurance ---------- 6
- Level of Protection ---------- 6

CHAPTER THREE—**FLOOD PROOFING MEASURES**
- Elevation ---------- 7
  - Elevation on Foundation Walls ---------- 7
  - Elevation on Piers ---------- 8
  - Elevation on Posts or Columns ---------- 8
  - Elevation on Piles ---------- 9
- Relocation ---------- 9
- Floodwalls and Levees (With/Without Closures) ---------- 9
  - Levees ---------- 10
  - Floodwalls ---------- 11
  - Closures ---------- 11
- Dry Flood Proofing ---------- 11
- Wet Flood Proofing ---------- 13

CHAPTER FOUR—**ASSESSING CHARACTERISTICS OF FLOOD SITUATIONS**
- Flooding Characteristics ---------- 14
  - Flood Depth ---------- 14
  - Flood Velocity ---------- 14
  - Flash Flooding ---------- 15
  - Ice and Debris Flow ---------- 15
- Site Characteristics ---------- 15
  - Site Location ---------- 15
  - Soil Type ---------- 16
- Building Characteristics ---------- 16
  - Building Foundation ---------- 16

- Building Construction ---------- 16
- Building Condition ---------- 16

Chapter Five—**The Evaluation Process**
- Physical Considerations ---------- 17
- Economic Considerations ---------- 18
- Aesthetics, Risk, and Other Considerations ---------- 18

Instructions for Figure 2 ---------- 21
References ---------- 22

Appendix A—How to Perform a Detailed Evaluation of Flood Proofing Options
- Evaluation of Individual Flooding Situation ---------- A-1
- Analyses of Benefits and Cost ---------- A-1
- Flood Hazard Information ---------- A-2
- What is in an FIS? ---------- A-2
- Other Sources of Flood Plain Information ---------- A-2
- Discharges ---------- A-3
- Flood Insurance Rate Map (FIRM) ---------- A-4
- Flood Profile ---------- A-4
- Flood Data Summary ---------- A-7
- Discharge Versus Elevation Curve (Rating Curve) ---------- A-7
- Discharge Versus Exceedance Probability Curve ---------- A-7
- Zero-Damage Level ---------- A-9
- Determine the First Floor Elevation ---------- A-11
- Depth Versus Damage Data ---------- A-11
- Probability Versus Damage Curve ---------- A-16
- Benefits of Flood Proofing ---------- A-16
- Flood Proofing Costs ---------- A-19
- Detailed Estimates of Flood Proofing Costs ---------- A-21

Appendix B—Worksheet and Graphs
- Worksheet ---------- B-1
- Graph—Discharge Versus Elevation ---------- B-2
- Graph—Discharge Versus Exeedance Probability ---------- B-3
- Graph—Probability Versus Damage ---------- B-4

Appendix C—Case Studies–Evaluating Flood Proofing Options
- Case A ---------- C-1
- Case B ---------- C-2
- Case C ---------- C-3
- Case D ---------- C-3
- Case E ---------- C-4
- Case F ---------- C-4

Tables
Table A-1 Summary of Discharges ---------- A-3
Table A-2 Flood Data Summary ---------- A-7
Table A-3 Depth-Damage Data for Example Home ---------- A-15
Table A-4 Flood Damage Prevented ---------- A-17
Table A-5 Present Worth Factors ---------- A-18

FIGURES

Figure 1 Flood Damage Reduction ---------- 1
Figure 2 Flood Proofing Matrix ---------- 20
Figure A-1 House Location on the FIRM ---------- A-4
Figure A-2 Stream Location on the FIRM ---------- A-5
Figure A-3 House Location on Flood Profile for Flat Rock Brook ---------- A-6
Figure A-4 Discharge Versus Elevation (Rating Curve) ---------- A-7
Figure A-5 Discharge Versus Exceedance Probability ---------- A-8
Figure A-6 Zero-Damage Level for Building with Openings Below First Floor ---------- A-9
Figure A-7 Zero-Damage Level for Building with Crawl Space Openings Below First Floor ---------- A-10
Figure A-8 Zero-Damage Level for Building with Window Wells ---------- A-10
Figure A-9 Depth Versus Damage for a Mobile Home Without Basement ---------- A-12
Figure A-10 Depth Versus Damage for a One-Story Home ---------- A-12
Figure A-11 Depth Versus Damage for a Split-Level Home ---------- A-13
Figure A-12 Depth Versus Damage for a Two-Story Home ---------- A-13
Figure A-13 Depth Versus Damage for Mobile Home Contents ---------- A-14
Figure A-14 Depth Versus Damage for Home Contents ---------- A-14
Figure A-15 Probability Versus Damage for Example Home ---------- A-16
Figure A-16 Computation of Fill ---------- A-21

CHAPTER ONE

INTRODUCTION

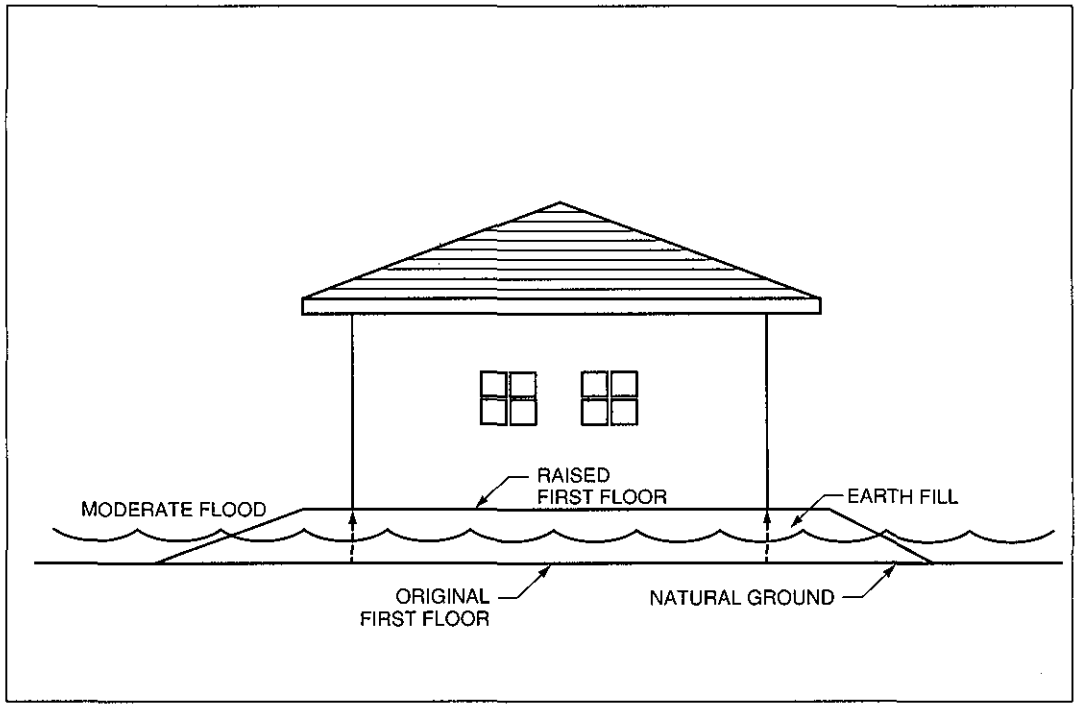
Flood proofing is defined as "any combination of structural or non-structural changes or adjustments incorporated in the design, construction, or alteration of individual buildings or properties that will reduce flood damages." Simply stated, flood proofing includes any effort property owners may take to reduce flood damage to buildings and their contents. Major impediments to flood proofing include apathy and lack of widespread knowledge regarding the subject. This document is dedicated toward the elimination of these impediments.

FLOOD DAMAGE REDUCTION

The potential for flood damage is determined by the depth of flooding and the number of times a building and its contents may be flooded. Flood proofing a building will decrease the potential for damage from future floods. Without flood proofing, a building is subject to damage from all floods that enter the basement or rise above the first floor level. With flood proofing techniques such as raising a building, floodwaters must rise to a higher level to cause damage. Figure 1 shows how raising a building can eliminate damage from moderate floods and reduce damage from larger floods.

Flood proofing can benefit the property owner in several ways. It will save money that would otherwise be spent to repair and clean up the building and its contents after a flood. In some cases, much of the contents require replacement. Also, damage prevented by flood proofing will reduce the inconvenience and annoyance caused by the time-consuming process of cleaning up and repairing a building. Other benefits of flood proofing may include less time off work, improved health and safety, and other intangible benefits.

FIGURE 1 — FLOOD DAMAGE REDUCTION



Effectiveness

The only method of flood proofing that will ensure complete safety from flood damage is relocating the building to a site outside of the flood plain. When buildings are not removed from the flood plain, flood waters may rise to an elevation that overcomes flood proofing measures causing even greater damages than would have been caused without flood proofing. Unless a building is relocated out of the flood plain, the building will still be exposed to some potential flood damage even if flood proofed.

Safety

Even after flood proofing, a building in a flood-prone location will still be subject to flooding if floodwaters overtop the flood proofing measures or if failure of the system occurs. Property owners must keep this in mind in order to avoid a false sense of security. No one should remain in a flood proofed building during a flood. This is hazardous and life-threatening. High velocity flows, waves, or other conditions can cause floodwaters to suddenly overtop the flood proofing leaving occupants little or no time or ability to vacate the building and flooded areas. In addition, rising flood waters may inundate all over-land means of escape.

Building Types

Some types of buildings are more suitable for flood proofing than others. The appropriate flood proofing methods will depend on the construction material of the building, such as brick or wood frame, and the nature of the building's design, such as the number of floors, basements, slab foundations, or crawl spaces. It is essential to know the type of construction of the building when analyzing potential flood proofing methods. A building totally unsuitable for one flood proofing method may be effectively flood proofed by another method. A variety of flood proofing options should be considered before concluding if a building is a candidate for flood proofing. Houses with basements, for example, generally provide a greater challenge to successful flood proofing.

CHAPTER TWO

SHOULD FLOOD PROOFING BE USED? THINGS TO CONSIDER

This chapter discusses the factors that should be considered in deciding whether or not to flood proof. Different factors will be more important to individual property owners depending on their financial situation, lifestyle, use of property such as home or business, and severity of their flooding problem.

FLOOD PROOFING ASSISTANCE

Technical and financial assistance may be available from Federal, State, or local governments and community agencies to help property owners regarding the practicality of flood proofing buildings. Property owners should investigate the availability of free technical and/or financial assistance in their initial flood proofing efforts and utilize such assistance as appropriate. The property owner will normally need to obtain paid technical assistance from a local architectural or engineering firm that has flood proofing experience prior to actually implementing a flood proofing measure.

Assistance is available from Federal agencies, such as the U.S. Army Corps of Engineers (COE), Federal Emergency Management Agency (FEMA), Department of Housing and Urban Development (HUD), Soil Conservation Service (SCS), Tennessee Valley Authority (TVA), and Small Business Administration (SBA), and from state and local agencies. More information on flood proofing assistance programs administered by various agencies and organizations, the points of contact for various agencies, and many other flood proofing reference documents is included in the COE National Flood Proofing Committee's document entitled *Flood Proofing Techniques, Programs, and References.* Federal agency documents are generally available from the specific agency's nearest field office. Other documents may be obtained from the Floodplain Management Resource Center at the Natural Hazards Center, IBS No. 6, Campus Box 482, Boulder, Colorado, 80309-0482 (Telephone No. 303/492-6818).

BUILDING CODES

Before property owners commit a significant investment of time and money in flood proofing, they should check local building codes to be sure that the flood proofing measure will be in compliance with these codes. Some communities require that all structural changes to buildings in the flood plain be approved by the local building authority; others will not issue building permits for structures within the flood plain in order to minimize future flood damages and to encourage the owners to move away from flood hazards. The National Flood Insurance Program (NFIP) administered by FEMA requires that if a building is substantially damaged by flooding (repair costs to restore the building to pre-damaged condition are 50% or more of the pre-damaged value), it must be rebuilt so that the lowest floor is above the 100-year flood protection level or removed from the flood plain altogether. The property owner should contact the local building inspector or city engineer for building code requirements and information on obtaining necessary permits.

COST ESTIMATES

The cost of flood proofing a building will depend on a variety of factors such as the characteristics of the building, the physical characteristics of the site, the flooding characteristics, and the flood proofing measure employed.

For most flood proofing measures, especially those involving elevating or relocating a building, it is recommended that an experienced contractor be hired. Before making a commitment to any work, the property owner should obtain a rough estimate of the cost of the flood proofing measure to assist in deciding whether further consideration is worthwhile.

In choosing a contractor, the property owner should look for those with experience in design and construction of flood proofing systems. The property owner should examine photos or make site visits to buildings previously flood proofed by the contractor to evaluate the quality of work. The property owner should obtain cost estimates from at least three contractors and question each about any price differences. The final decision on selecting a contractor should be based not only on cost but also on the ability of the contractor to complete the project in a satisfactory and timely manner.

Before work on flood proofing the building begins, a contract between the property owner and the contractor should be signed to be sure that there is mutual agreement on the work to be performed and how it will be funded. The property owner should never sign a vague contract and should always obtain a copy of the final signed contract. The property owner may wish to consult with a lawyer before signing the contract, especially for more complex and costly projects. After the work is completed and before final payment is made, the property owner should be satisfied with the work, make sure that all appropriate regulatory requirements and inspections have been satisfied, and obtain written assurance that all subcontractors and suppliers of material have been paid.

If the flood proofing project is expected to require design by a professional engineer, the property owner should hire an architectural/engineering (A/E) firm for technical assistance. As with selecting a contractor, the property owner should choose an A/E firm not only based on price but also on the ability to perform the work in a timely manner. The A/E firm should be able to provide a list of similar, completed projects including photos and/or the names and addresses of the clients. The property owner should visit completed projects and/or call the clients to ask questions and evaluate the quality of work. The firm should also be located in and have knowledge of the project area, including necessary permit requirements and availability of qualified contractors.

The names of qualified contractors and A/E firms who work in flood proofing may be obtained through the local Better Business Bureau, building associations, and the Independent Contractors Association.

Secondary Benefits

Primary flood proofing benefits are those discussed under the Flood Damage Reduction section in Chapter One. Secondary benefits that property owners realize from flood proofing may not be readily apparent to them, particularly if they have not previously experienced flooding. For homeowners, these secondary benefits might include avoiding the expense and inconvenience of staying elsewhere after suffering flood damages that could have been avoided by flood proofing, reducing the hours they must spend away from their jobs while cleaning and repairing the flood-damaged building, and preserving the structure itself which would increase the life of the building. The resale value of a structure subject to flooding may be enhanced by reducing the new property owner's anxiety from fear of repeated flooding. A flooded business could result in loss of wages, reduced profits, or delays in receiving goods and services.

Inconvenience

There is also great personal inconvenience experienced by property owners who are flooded. In many cases, they cannot occupy the building until they clean and repair the flood damage. Restoration can include repairing sagging floors and roof sections, drying

out the building, removing debris, draining standing water, removing mud, and fixing leaky pipes. The property owner may also have to file insurance claims and disaster assistance applications. Damaged household and personal items such as clothes, furniture, and appliances will have to be cleaned or replaced. Utilities must be restored and structural repairs made to the building, normally by service professionals. Also, floods can destroy irreplaceable items such as photographs, family heirlooms, and business records. Much of this inconvenience can be reduced or limited if the property owners flood proof their buildings.

Health and Safety

Flooded buildings expose occupants to a variety of health hazards. Sewer lines may back up and flood the building. Rats and snakes may also temporarily inhabit the flood-damaged building. The water supply could become contaminated. Food, medicine, and cosmetics that have been touched by floodwaters will be spoiled. Occupants may also be exposed to electrical shock from outlets or appliances when attempting to reenter a building after a flood. Floodwaters may cause cracks in gas pipes in the building, resulting in gas leaks and possibly fires. In addition, coping with the aftermath of a flood can cause considerable stress. Property owners may suffer loss of sleep or fatigue. Many of these hazards can be avoided by flood proofing.

Architectural Aesthetics

The property owner may wonder, "How will my building look if I flood proof? Will it look strange?" This is an important consideration. With the help of an architect, flood proofing can be integrated with the design of the building to create a pleasing appearance. In some cases, the beauty of a building can be enhanced.

Another consideration regarding building appearance occurs after the flood has subsided. If the building is not flood proofed, the property owner must repair and restore it, as described previously. During this often lengthy period, the building may be unusable. On the other hand, if the building is flood proofed, the cleanup work after a flood will likely involve only landscaping repairs to the damaged yard. A flood proofed building can usually be restored to its pre-flood condition fairly quickly at a relatively low cost.

Emergency Measures

If standard flood proofing measures turn out to be impractical, there are other actions that the property owner may take to reduce flood damage. In general, greater reductions in flood damage may be achieved by working with someone experienced or trained in emergency flood protection measures. If there is sufficient warning prior to a flood, the property owner can relocate items such as electronic equipment, furniture, and personal items from the basement or first floor to a higher level above the expected flood elevations. These items may also be transported to a safe location away from the property. Also, if there is ample warning the property owner can implement emergency flood protection measures such as sandbagging around windows and doors or boarding up entrances to the home. However, such measures should not exceed three feet above the first floor level. Floodwater depths greater than three feet on a building can result in hydrostatic pressures great enough to damage or collapse the walls of the building.

Flood Insurance

Flood insurance coverage is available from the National Flood Insurance Program (NFIP) to all owners and occupants of insurable property (buildings and their contents) in communities that participate in the NFIP.

Walled and roofed buildings that are principally above ground and not entirely over water may be insured if they are located in a participating NFIP community. Flood insurance is available to all buildings in a participating community whether the buildings are in or out of the flood plain. This coverage is also available for manufactured homes that are anchored to permanent foundations. Up to 10 percent of the policy value for building coverage may apply to a detached garage or carport on the same lot. Contents within insurable walled and roofed buildings also may be insured under a separate coverage. An NFIP policy does not cover items such as paneling, carpeting, furniture and contents in the unfinished portion of a basement or enclosure underneath an elevated building, travel trailers, converted buses or vans, valuable papers, and land values.

The purchase of flood insurance is required for buildings located in a special flood hazard area as a condition of having a Federally-backed mortgage or home improvement loan, and obtaining Federal disaster assistance. NFIP flood insurance is available through private insurance companies and agents. All companies offer identical coverage and rates.

Insurance rates for new structures are set on the basis of designated flood hazard zones and the elevation of the building or structure in relation to the expected flood level in that particular location. This rate structure provides an incentive to property owners to elevate buildings in exchange for receiving the financial benefits of lower insurance rates.

Any new or substantially improved (including substantial damage) residential building must be elevated to or above the base flood elevation (BFE). Flood proofing (other than elevation) is not recognized as meeting this NFIP requirement. A residential building is considered to be substantially improved when the cost of any reconstruction, rehabilitation addition or other improvements equals or exceeds 50 percent of the value of the building. Elevating a building above the BFE does not eliminate the requirement to purchase flood insurance unless the property is removed from the special flood hazard area by obtaining a Letter of Map Revision (LOMR). Even though a building is elevated, the potential exists for residual damage or a catastrophic event that exceeds the BFE.

Almost all of the nation's communities with serious flooding potential have joined the NFIP. Property owners who do not presently have flood insurance should consider purchasing a flood insurance policy if they are located in a flood prone area. While damages to the building and its contents from flooding are not always preventable, flood insurance will lower the financial burden to the property owner when damage occurs. To find out if flood insurance is available in their community, property owners should contact their insurance agent or local building official. Property owners who already have flood insurance should find out whether the coverage is adequate.

Level of Protection

Flood proofing measures may be designed to provide different levels of protection depending on the factors discussed in this document. Level of protection is generally defined by the probability (percent chance) of flood magnitude required to exceed the capability of the flood proofing measure in any given year. Annual exceedance probabilities are expressed in decimals less than 1.0, such as 0.10, which means one chance in ten. A more likely flood with a probability of 0.5 would be equivalent to one chance in two. Companion terms for these probabilities are flood frequency in average numbers of years, i.e. 10-year and 2-year. The level of protection may be constrained because of depth of water, velocity of water, condition of the building, site conditions, cost of flood proofing, etc.

CHAPTER THREE

FLOOD PROOFING MEASURES

Flood proofing may be designed to either reduce the number of times the building is flooded or limit the potential damage to the building and its contents when it is flooded. There are three general approaches to flood proofing:

- Raising or moving the building
- Constructing floodwalls or levees to stop floodwaters from entering the building
- Modifying the building and relocating contents to minimize flood damage

Specific types of flood proofing are briefly reviewed in this chapter. More detailed information regarding the various flood proofing measures is available from the Floodplain Management Resource Center at the Natural Hazards Center in Boulder, Colorado, referenced in Chapter Two.

ELEVATION

Elevation involves raising the building in place so that the lowest floor is above the flood level for which flood proofing protection is provided. The building is jacked up and set on a new or extended foundation.

Almost any structurally sound building can be elevated. Typically, the least expensive and easiest building to elevate is a one-story frame building built over a crawl space that is 18 inches or higher. The process becomes more difficult and expensive as different factors are added, such as a building with a basement, a slab-on-grade building, a building constructed of brick or block, a multi-story building, or a building with additions.

Property owners wishing to use this method should employ a contractor to ensure that the building is properly raised and a safe foundation is constructed. The elevated foundation must be able to withstand erosion caused by floodwaters and the impact caused by ice and debris in floodwaters. It is also advisable to have the building inspected by a structural engineer prior to elevation to assess the structure's ability to undergo elevation.

Buildings can be elevated on several different types of foundations, including raised foundation walls or an open foundation. Elevating a building on an open foundation involves raising it onto piers, posts (columns), or piles. If the building is located in an area of coastal flooding, an open foundation is the only way to safely elevate. If the building is subject to high-velocity floodwaters, significant water depths, or potential erosion, the property owner should also consider having the building elevated on an open foundation. Doing so will allow the waters to flow beneath the building and reduce potential damaging impacts.

Elevation on Foundation Walls

Elevation on this type of foundation is normally used in areas of low to moderate water depth and velocity. After the building is jacked up, existing foundation walls can be extended vertically using materials such as masonry block or poured concrete. The building is then set down on the extended walls. While elevating on foundation walls is often the easiest solution to the problem of flooding, there are several important considerations. The most important concern is that the original foundation and footing

must be able to withstand the extra loading, not only from the additional vertical dead load of the new wall, but also from the additional flood forces. If the footings are not deep and wide enough, they may be unable to resist the additional loads, which could result in overturning or undermining of the walls and subsequent collapse of the building. In addition, the original foundation walls may not be thick enough to be extended. A structural or foundation engineer can help make these determinations.

Depending on the potential flood forces, it will usually be necessary to reinforce both the footings and walls using steel reinforcing bars. An equally important concern regarding new foundation wall construction is how it is connected to the existing superstructure of the building. Regardless of what type of foundation wall construction is used, hydrostatic and hydrodynamic forces can result in collapse of the building. In order to eliminate the danger, foundation walls may need to be constructed with openings or vents, to allow flood waters to equalize the hydrostatic forces.

A potential solution to the problem of excessive hydrodynamic forces on foundation walls is to elevate the building on only two walls, spanning the building between them and leaving the two ends open. By orienting the walls parallel to the flow of water, the amount of wall area resisting the forces from flood water velocity is less and loading is significantly reduced. In many cases the ends are not left totally open. For aesthetic or security reasons, it may be desirable to enclose the area. This can be accomplished by installing lattice work or light weight walls that are designed to break off during floods.

Elevation on Piers

The most common example of an open elevation support structure is the pier. Piers are vertical structural members that are supported entirely by reinforced concrete footings. While they may be the most commonly used type of foundation, they are the least suited for withstanding flood forces. In conventional use, piers are designed primarily for vertical loading. When exposed to flooding, however, they will also experience hydrodynamic forces. For this reason, piers used in flood proofing to support an elevated building must be not only substantial enough to support the structure, but also sufficiently reinforced to resist a range of flood forces.

Piers are generally used in shallow depth flooding conditions with low velocity flow, and are normally constructed of either masonry block or poured-in-place concrete. In either case, they should have steel reinforcing both in the pier itself and in the footing providing support; the reinforcing should be tied together to prevent separation. There must also be suitable connection between the superstructure and piers to resist wind and buoyancy forces.

Elevation on Posts or Columns

When flooding is characterized by moderate depths and velocities, elevation on posts (also referred to as columns) is a frequently used flood proofing method. Posts are generally square, since this shape is easier to attach to the structure, however round posts may also be used. Posts are made of wood, steel, or even precast reinforced concrete. They are set with their ends into pre-dug holes, and material such as earth, gravel, or crushed stone is backfilled around them. Since substantial loading is usually expected, posts are normally anchored into a concrete pad at the bottom of the hole.

While piers are designed to act as individual support units, posts normally must be braced. There are a variety of bracing techniques, using several different materials. The type to be specifically employed on an elevated residence in a particular area depends on local flood conditions and loads. Some of the more commonly used bracing techniques include wood knee and cross bracing, steel rods, and guy wires.

Elevation on Piles

Where high-velocity flooding can result in scouring (erosion of supporting material), piles provide the best type of foundation. Piles differ from posts in that piles generally are more slender and are mechanically driven deeper into the ground. Because of this, piles are less susceptible to the effects of high-velocity flood waters and scouring. Piles must either rest on a support layer such as bedrock or be driven deep enough so that there is enough friction between the pile and the surrounding soil to carry the load. Piles are generally made of wood, although steel and reinforced precast concrete are also used. They often require bracing similar to the methods described for posts.

Because driving piles generally requires bulky machinery, an existing building that is being flood proofed will have to be temporarily moved aside and set on cribbing until the driving of piles is complete. This additional cost may preclude the use of piles in the selection of a flood proofing elevation method.

Relocation

Relocating a building is the most dependable, but generally the most expensive, way to flood proof. This method involves moving the building to another location away from flood hazards, either to a higher elevation on the existing lot or to a new site. Relocating a building out of the flood plain is appropriate if the building is in an area where flood hazards are such that continued occupation is unsafe. It is also an option for the property owner who wants to be free from the damages, fear, and worry associated with flooding.

This procedure involves raising the building, as described in the above section on "elevation" and placing it on wheels. The building is then transported to a new location and placed on a new foundation.

Property owners should consider many factors before deciding to relocate, including the building's structural soundness and whether there are bridges or other obstructions along the transportation route. During the move, property owners and their families must live elsewhere, perhaps for several weeks, and may need to store furniture and belongings temporarily.

Normally, cost is the major concern associated with building relocation. In addition to paying the moving contractor, the property owner may need to purchase a new lot (if the owner is not staying on the present lot), build a new foundation, relocate utilities, landscape, and pay for professional services and fees.

Floodwalls and Levees (With/Without Closures)

Floodwalls and levees are freestanding structures located away from the building that prevent the encroachment of floodwaters. They may completely surround the building or protect only the low side of the property. Unlike other flood proofing measures, a well designed and constructed freestanding floodwall or levee results in no water pressure on the house itself. Consequently, as long as the floodwall or levee holds or is not overtopped, the building should not be exposed to damaging hydrostatic or hydrodynamic forces. Another advantage with this technique is that there is no need to make major structural alterations to the building.

Floodwalls and levees require periodic maintenance, including removing debris from any check valves on pump discharge pipes after each storm, and inspecting the sump pump for proper operation. In addition, the property owner will have to inspect levees for signs of erosion, settlement, animal burrows, and trees. Floodwalls need inspection for signs of cracking and spalling. Construction of floodwalls

and levees may require local, state and/or Federal permits. These permits are generally needed to protect other properties from any adverse impacts, to avoid filling in wetlands, and to maintain regulatory floodways. Therefore, the need for such permits should be investigated early in the planning process to avoid last minute delays, redesign of the protection, or changing to an alternate flood proofing measure.

While it is possible to design floodwalls and levees for large flood forces associated with major flood protection projects, flood proofing measures are generally restricted to a height of six feet or less. This restriction is usually necessary because of limited space, cost, visual concerns, and less complex design analysis.

The most important consideration of all is that the property owners who have constructed a floodwall or levee should not have a false sense of security about their property protection. Every flood is different, and the one that exceeds the design height and overtops the floodwall or levee can happen at anytime. For this reason, the protected area should always be evacuated prior to flooding.

If a floodwall or levee fails due to overtopping, damage to the protected structure will be as great or greater than if no protection was provided. Additional damage could result because it takes longer to remove the flood water from the inside of the floodwall or levee once flood levels subside.

Levees

Typically, levees are constructed of compacted fill taken from locally available impervious soils. Depending upon the availability of suitable local soil, levees may be one of the least expensive of all flood proofing measures. Levees are usually built parallel to the river and extend to high ground when it is available. Levees have the advantage of being compatible with the landscape since they are easy to shape. The property owner can plant grass and other forms of light vegetation on an earthen levee to help prevent erosion and provide aesthetic enhancement. Impervious earth can also be constructed against a building in lieu of a free standing levee and pleasingly landscaped. This could be considered a dry flood proofing technique.

Although levees may be attractive in terms of economics and appearance, they have a number of distinct drawbacks that may make them impractical for many property owners. One potential problem is that levees can impede the natural flow of water in a flood plain, possibly resulting in increased flooding of adjacent property. Similarly, they can also block the natural drainage from surrounding property.

Another major drawback is that levees take up a great deal of property space. To minimize erosion and to provide adequate stability, their embankment slopes must be fairly gentle, usually a ratio of one vertical to two or three horizontal. Because of this, a levee's width will be several times its height.

An important factor in determining the feasibility of a levee involves the availability of suitable fill material for the levee, as well as the adequacy of the underlying soil that must support the levee. Most types of soils are suitable for constructing levees. The exceptions are very wet, fine grained, or highly organic soils. The best soils are those which have a high clay content, and are therefore highly impervious. Impervious soils minimize seepage problems either through or under the levee system.

In those cases where suitable fill material is not locally available, the expense of transporting proper material to the site can be significant. This additional cost could be a major factor in determining the feasibility of this option. While all levee slopes should have vegetation, one way to further protect a levee from erosion is to armor the vulnerable areas with resistant material such as stone riprap.

Floodwalls

Similar to levees, floodwalls also keep water away from the building. However, floodwalls are constructed of stronger materials, are thinner, take less space, and generally require less maintenance than levees. Floodwalls can be constructed using a variety of designs and materials. By taking into account the individual building design, siting, and topography, and with some imagination, a floodwall can be constructed that not only protects a building, but also enhances its appearance.

Selection of a floodwall design is primarily dependent on the type of flooding expected at the building site. Tremendous forces can be created by high flood levels and flood velocities. Fast moving water can also be a danger since erosion might undermine the floodwall or its footing and cause a failure, therefore, riprap may be needed to prevent this problem.

Closures

Closures must be provided for sidewalks, driveways, and other openings left in a floodwall or levee. However, floodwalls and levees designed without closures are normally more effective because there is no need for human intervention. In the case of a levee, access may be provided simply by constructing the levee with gentler side slopes at the driveway to allow vehicles to enter and exit by passing over the levee. When constructing a floodwall or levee around a building, a sump pump must be incorporated to provide proper interior drainage from groundwater seepage and rainwater from the building side of the protection.

Closures act to close the openings in floodwalls and levees and prevent water from entering. They can be of a variety of shapes, sizes, and materials. In some cases closures are permanently attached using hinges so that they can remain open when there is no flood threat. They may also be portable, normally stored in a convenient location and slipped into place when a flood threatens. There are a number of elements involved in designing and using a closure system. Closures may be separated into two basic categories: permanent or temporary. Combinations of permanent and temporary closures are also feasible.

Closures can be considered as an option only if a flooding situation provides sufficient warning time to properly install them. The need for both sufficient warning time and "human intervention" is critical, since all temporary closure systems require personnel to install them and make certain they are properly sealed.

Closures that are stored between floods must be readily accessible. The effectiveness of an entire system will be compromised if the closures are stored such that flooding renders them inaccessible, or if even one closure is improperly installed. Closure systems are most effective where there are a limited number of openings. If there are too many, leakage could overwhelm and defeat the system. Any sewers or drain pipes passing through or under a floodwall or levee will require closure valves to prevent backup and flooding inside the building and protected area.

Dry Flood Proofing

Dry flood proofing involves sealing building walls with waterproofing compounds, impermeable sheeting, or other materials and using shields for covering and protecting openings from floodwaters. In areas of shallow, low velocity flooding, shields can be used on doors, windows, vents, and other building openings. The first step with the use of shields placed directly on buildings is to be certain that both the shield and the building are strong enough and sufficiently watertight to withstand flood forces. Sewer lines should be fitted with cutoff or check valves that close when flood waters rise in the sewer, to prevent backup and flooding inside the building.

Dry flood proofing is not generally recommended for buildings with a crawl space or basement, because these types of structures are susceptible to underseepage, which can result in significant "uplift" or buoyancy forces and create serious design problems. Generally, dry flood proofing should only be employed on buildings constructed of concrete block or brick veneer on a wood frame. Weaker construction materials, such as a wood frame, will fail at much lower water depths from hydrostatic forces. Even brick or concrete block walls should not be flood proofed above a height of three feet, due to the danger of structural failure from hydrostatic forces.

Some waterproofing compounds cannot withstand significant water pressure or may deteriorate over time. For effective dry flood proofing, a good interior drainage system must be provided to collect the water that leaks through the sealant or sheeting and around the shields. These systems can range from small wet-vacs to a group of collection drains running to a central point from which water is removed by a sump pump. Property owners considering dry flood proofing should consult a professional engineer to analyze hydrostatic forces that can cause structural damage to walls and floors. Though dry flood proofing may seem simple, it is a sophisticated method that requires full understanding of the possible dangers stemming from poor planning, design, or installation.

Most wall materials, except for some types of high-quality concrete, will leak unless special construction techniques are used. These techniques require a high level of workmanship if they are to be effective. The most effective method of sealing a brick faced wall would be to install a watertight seal behind the brick when the building is constructed. For flood proofing existing structures, the best way to seal a wall is to add an additional layer of brick with a seal "sandwiched" between the two layers. It is possible to apply a sealant to the outside of a brick or block wall, but any coating must be applied carefully. Cement or asphalt based coatings are the most effective materials for sealing a brick wall, while clear coatings such as epoxies and polyurethanes tend to be less effective. As a result, the aesthetic advantages of a brick wall are lost with the use of better sealant coatings.

The difficulty and complexity of sealing a structure also depends on the type of foundation, since all structural joints, such as those where the walls meet foundations or slabs, require treatment. For very low flood levels, such as a few inches of water, a door can be flood proofed by installing a waterproof gasket and reinforcing the door jamb, hinge points, and latch or lockset and coating it with a waterproof paint or sealant.

If there is a chance of higher flood levels, some type of shield will be needed. If the expanse across the door is three feet or greater, the shield will have to be constructed of heavy materials, such as heavy aluminum or steel plate. The resulting weight may require the shield to be permanently installed, using either a hinged or slide-in design. The frame for such an installation must be securely anchored into the structure. When windows are exposed to flooding, some form of protection is needed because standard plate glass cannot withstand flood forces. One solution is to brick up all or part of the window. It may also be possible to use glass block, instead of brick, to admit light.

For normal-sized windows, shields can also be used. They should be made of materials such as heavy plexi-glas, aluminum, or framed exterior plywood. These can be screwed in place, or slid into pre-designed frame slots. Another alternative is to replace the glass with heavy plexi-glas; however, the window must be sealed shut and waterproofed using water resistant caulking.

Wet Flood Proofing

If dry flood proofing is impossible or too costly, another option is wet flood proofing, which allows the structure to flood inside, while ensuring that there is minimal damage to the building and contents. Interior flooding allows water forces on the inside of the building walls to counteract the hydrostatic forces on the outside, thus reducing the chance of structural damage. When the structure is designed for wet flood proofing, vulnerable items, such as utilities, appliances, and furnaces, should be relocated or waterproofed with plastic bags and sheeting. Utilities and appliances may be moved permanently or temporarily to a place in the building higher than a selected flood level—either to existing space, such as the attic, or to a small addition that would serve as a utility room. Wet flood proofing the contents of commercial buildings may require special considerations because of their unique nature.

If there is no space for relocating utilities, appliances, and other contents, they may be protected in place. In the case of very shallow flooding, a mini-floodwall built around these items would provide protection. For deeper waters, they could be elevated on a platform or suspended overhead from floor or ceiling joists.

The property owner must have sufficient warning time to employ wet flood proofing methods by temporarily moving items. If the building is subject to flash floods, this method may not work. In addition, the property owner must be aware that flooding an area containing a source of electricity or hazardous materials can be dangerous. Also, clean-up will be required after each flood.

The owner of a wet flood proofed building may choose to flood the basement with a clean, potable water source (such as with a garden hose from a faucet) before floodwaters reach the building. This would reduce the amount of contaminated floodwaters entering the building and minimize health concerns, clean-up time, and costs.

CHAPTER FOUR

ASSESSING CHARACTERISTICS OF FLOOD SITUATIONS

When evaluating the possibility of flood proofing, consideration must be given to the characteristics of the flooding that affect the building. These characteristics, along with the characteristics of the site and the building, suggest the most effective and feasible flood proofing options.

FLOODING CHARACTERISTICS

Flood Depth

A building is susceptible to floods of various depths, with floods of greater depth occurring less frequently than floods of lesser depths. Potential flood elevations from significant flooding sources are shown in flood insurance studies for communities participating in the NFIP. For the purpose of assessing the depth of flooding likely to impact a structure, it is convenient to use the flood levels shown in FISs, historical flood levels, and/or flood information from other studies and reports. The depth of flooding affecting a structure can be calculated by determining the height of the flood above the ground elevation at the site of the structure.

If a building is subject to flooding depths greater than three feet, elevating or relocating the structure are the most effective measures of flood proofing. Other measures may not be as appropriate because water depths greater than three feet may cause hydrostatic forces high enough to render structural damage or cause wall collapse. Flood proofing with levees and floodwalls for depths greater than three feet can be undertaken, but may require structural devices to control flow under the levee or floodwall as well as other expensive methods.

If a well constructed building is subject to flooding depths less than three feet, hydrostatic forces are not as significant. Therefore, consideration can be given to using barriers, sealants, and closures for flood proofing. If shallow flooding causes a basement to fill with water, wet flood proofing can be used to reduce flood damage. Special devices are available to prevent basement flooding due to water back-up through sewers.

Flood Velocity

The speed at which flood waters move—the flood flow velocity—is normally expressed in terms of feet per second (fps). As floodwater velocity increases, hydrodynamic forces are added to the hydrostatic forces from the depth of still water, significantly increasing the possibility of building failure. Greater velocities can quickly erode or scour the soil surrounding buildings. These fast-moving waters can also result in structural failure by erosion and their impact may move a building from its foundation. When floodwater velocities exceed three fps, it becomes difficult, if not impossible, for adults to maintain their balance while walking through a flooded area. Unfortunately, there is usually no readily available source of information to determine potential flood velocities in the vicinity of specific buildings. Historical information from past flood events is probably the most reliable source. If personal knowledge of past flood erosion and/or movement of structures is not available, others in the neighborhood may be able to provide this type of information. If specific information on flood velocities is available and indicates that the building is subject to flood waters with velocities greater than three fps, professional advice is critical in the selection of an appropriate flood proofing measure.

Flash Flooding

In areas of steep topography and/or a small drainage area, floodwaters can rise very quickly with little or no warning. This condition is known as flash flooding. High velocities usually accompany flash flooding and may preclude certain types of flood proofing. In a flash flooding situation, damage usually begins to occur within one hour after significant rainfall. If a building is susceptible to flash floods, insufficient warning time can preclude the use of any flood proofing method requiring human action, such as installing closures on windows, doors, or floodwalls. Temporarily relocating moveable contents to a higher level may also be impractical. However, these methods may be effective if a building is not subject to flash flooding and the area has adequate flood warning systems, such as warnings broadcast on television and radio. In areas of long duration flooding, certain methods such as dry flood proofing may not be as applicable because of the increased chance for seepage and failure due to prolonged exposure to flood water.

Ice and Debris Flow

In colder climates chunks of ice from ice breakup can be carried in flood waters and act as a battering ram causing serious building damage. During flood periods with freezing temperatures, ice can also form around the building. If floodwaters rise and the ice is thick enough, and attached well enough to the building, lifting can occur and cause severe damage. Flood waters often carry debris, such as boulders, rocks, and trees, that can destroy most flood proofing measures, as well as the building itself.

If a building is subject to ice or debris flow, flood proofing measures involving elevation require the services of a professional engineer to ensure that the building structural supports can withstand the impact of ice or debris flow. Flood proofing measures involving sealants and/or closures should not be used if the building is in an area of ice and debris flow.

Site Characteristics

Site Location

Coastal flooding is normally caused by large storms such as hurricanes that cause abnormally high tides. High tides, coupled with wave action from high winds, often cause damage more severe than that brought on by river or lake flooding. If a building is subject to coastal flooding, elevating the structure on piles, posts, or piers, or relocation are the only feasible flood proofing measures. The destructive force of wave action will generally destroy other types of flood proofing.

Riverine flooding results from heavy or prolonged rainfall, snowmelt, or combined runoff from the drainage area. As rain falls and/or snow melts, portions of this water will soak into the ground, collect in local depressions, or evaporate. Remaining water will run off the land and collect in small streams. As this water moves downstream, several tributaries combine, increasing the total amount of water contributing to floods. Eventually, these streams empty into rivers, lakes, and oceans. Under certain conditions, such as rainfall of high intensity or long duration, the amount of runoff will result in water depths that exceed the normal capacity of the stream, river, or lake, causing flooding that may damage property.

Soil Type

Permeable soils, such as sand, are those that allow groundwater to flow freely. If a building has a basement and is located on permeable soil, flood proofing measures involving sealants and closures are usually ineffective because the permeable soil will allow groundwater to increase forces along the basement walls, causing seepage and/or structural damage to the building. Buildings with crawl spaces will have seepage problems while those with concrete slabs will experience uplift when constructed on permeable soils. Water will pass under floodwalls and levees constructed on permeable soil unless expensive seepage control measures are included as part of the flood proofing. Other problems with soil that is saturated with flood waters also need to be considered. If a building is located on unconsolidated soil, wetting of the soil may cause uneven (differential) settlement. The building may then be damaged by inadequate support and pulling or bending forces. Some soils may expand when exposed to floodwater and cause pushing forces against basement walls and floors. Thus, serious damage can occur even though floodwaters do not enter the structures. To determine if a building is sited on permeable or other flood impacted soil, contact the local office of the SCS or a local geotechnical engineering firm. Technical expertise is required to resolve problems associated with adverse soil conditions.

Building Characteristics

Building Foundation

There are three basic types of foundations for structures, which may be utilized individually or in various combinations. They are slab-on-grade, crawl space with the building supported on foundation walls, and basements with poured concrete walls and floors or masonary walls and poured concrete floors. Each type of foundation has its own advantages and limitations when flood proofing measures are being evaluated. All types of flood proofing can be considered for slab-on-grade and crawl space foundations. However, the crawl space foundation generally provides for more economical elevation and relocation flood proofing measures. Buildings with basement foundations often require more involved flood proofing measures and are not recommended for some types of flood proofing.

Building Construction

Most buildings are constructed of concrete and masonry or wood. However, other materials such as aluminum, vinyl, and fiberglass are also used. Combinations of these materials may be used in the construction of a single building. Thus, the suitability of applying a specific flood proofing measure can be difficult to assess. Concrete and masonry construction can be considered for all types of flood proofing measures, whereas, other materials may not be structurally sound. When classifying building construction as concrete and masonry, it is important that all walls and foundations be constructed of this material. Otherwise, there may be a weak link in the flood proofing measure resulting in potential for failure. For general consideration of flood proofing measures, all construction should be classified with wood material unless all walls and foundations are concrete and masonry.

Building Condition

Building condition may not be easy to evaluate as many structural defects are not readily apparent. However, careful inspection of the property should provide for a classification of "excellent to good" or "fair to poor." This classification is only for the reconnaissance phase of selecting an appropriate flood proofing measure(s). More in-depth planning and design may alter the initial judgment regarding building condition and eliminate consideration of some flood proofing measures.

THE EVALUATION PROCESS

Physical Considerations

The evaluation of applying flood proofing measures to buildings may begin with an individual owner or a government agency with flood plain management responsibilities. Motivation for the evaluation generally comes from actual flood events, which cause damage to homes and other buildings located in the flood plain. However, some property owners may be motivated by the knowledge that their buildings are located in the flood plain and have significant potential for flood damage. This knowledge is often obtained from flood insurance studies published by FEMA or flood hazard information studies performed by other Federal agencies such as the COE, USGS, and SCS. When interest in flood proofing measures is stimulated, a search for knowledge about flood proofing begins. Chapters 1 and 2 provide general information on flood proofing considerations and where to obtain additional documents on specific aspects. Chapters 3 and 4 provide more detailed information on each flood proofing measure and physical characteristics that influence the feasibility of applying specific measures to an individual building at a specific location.

Figure 2, shown on page 20, contains a flood proofing matrix that can be used to evaluate which flood proofing measures are appropriate for individual buildings. This matrix involves the determination of the nine characteristics pertinent to the building being evaluated. Some characteristics are more difficult to evaluate than others; therefore, the initial effort should involve determination of the characteristics which require the least effort. For example: A quick appraisal of a building being considered for flood proofing indicates it to be in "Fair to Poor" condition. Using Figure 2, this information eliminates all flood proofing measures except "Floodwalls and Levees" by assigning N/A (non-applicable) to the other measures. The evaluation process continues by making a check of other characteristics that could eliminate the use of "Floodwalls and Levees." Flood depth was found to be 4 feet, the flood duration was more than 1 hour, there was no ice or debris involved, and the site was riverine with impermeable soil. Thus, the examination indicates that the only other example characteristic that would eliminate the "Floodwalls and Levees" measure is "Fast Flood Velocity." The determination of flood velocity for the example is 7 fps, which designates a fast condition and eliminates the "Floodwalls and Levees" measure. The evaluation of the example matrix indicates that flood proofing measures should not be applied. However, the matrix is a guide; not an absolute decision process. In the example case, a floodwall or levee will be effective if special design features are incorporated to avoid erosion from the fast flood velocity. Thus, the decision process illustrates how a satisfactory flood proofing measure can often be adopted when the initial appraisal indicates that flood proofing would not be advisable.

Another example illustrating a best case condition is when all nine flooding characteristics have no N/A designations. This indicates that any of the flood proofing measures could be applied to the building with reasonable expectation of reducing flood damage. Some measures would be more effective for reducing damage than others and costs would vary with the method selected. Detailed engineering analysis is needed in most evaluations to assure the physical feasibility of flood proofing measures indicated by application of the flood proofing matrix. Some of the less involved wet flood proofing actions could be applied without professional engineering analysis. However, simple applications such as flood shields on doors and windows need to be professionally evaluated to be sure that flood forces would not cause structural failure.

Economic Considerations

The total cost of flood proofing measures includes operation and maintenance as well as future replacement costs. This total cost and expected reduction in future flood damages from the flood proofing measures are important to building owners and government entities funding flood proofing projects. Detailed benefit/cost analysis is generally not required for property owners to make decisions regarding the application of flood proofing measures; however, they need some assurance that costs are within their means and that damages prevented will be significant. Appendix A provides an in-depth procedure for evaluating the benefits and costs of the various flood proofing measures; Appendix B includes work sheets for the economic analysis; and Appendix C provides hypothetical cases of how different property owners might evaluate flood proofing options available to them. Included are some brief examples on evaluation of costs and flood damage prevented.

Communities and water resource agencies are interested in reducing flood damage by various means such as flood control projects, flood plain management, and flood proofing. When Federal, state, or local resources are considered for flood reduction projects, economic feasibility is normally an important consideration. Appendix A contains appropriate methodology for evaluating the economic feasibility of flood proofing individual buildings, which can then be aggregated to evaluate community projects involving the flood proofing of many buildings within a specified flood plain area. The methodology can also be used by individual building owners (with professional assistance) when making personal decisions whether or not to flood proof.

Aesthetics, Risk, and Other Considerations

Although physical and economic considerations can help determine feasible flood proofing measures for individual buildings, they may not be the most important factors being evaluated by the owner (ultimate decision maker). For example, a flood proofing measure that scores high for all other considerations except aesthetics may be rejected by the owner no matter how influential professional advice may be.

Aesthetics relate to the appearance of a building after it has been elevated on fill, the integration of a levee with surrounding landscape, the preservation of a scenic view, or other revisions that may significantly alter existing appearance. Building owners should insist that consulting engineers and contractors provide good visual representation of how a proposed flood proofing measure will affect a building's appearance. Computer programs and video equipment can provide realistic simulations of future appearance at reasonable cost.

Another element that should be included in the evaluation of flood proofing measures is the risk associated with a do-nothing approach as related to adopting a flood proofing measure. Risk can also be established among flood proofing measures by knowing the exceedance probability of floods and the design flow levels for competing flood proofing measures. Relocation is an example of how flood proofing can eliminate risk of flood damage. On the other hand, a levee designed to protect against a 10 percent chance annual exceedance probability (10-year) flood would have an 88 percent chance of being overtopped during a 20-year period. Such information assists the building owner in evaluating the pros and cons of each flood proofing measure and making wise choices.

Flood probabilities are also useful in determining the inconvenience aspects of flood proofing. Reducing cleanup and repairs, lost time from work, and average non-use of a building from once in two years to once in ten years could be a powerful inducement for flood proofing, even though other aspects may be less convincing.

Appendix C provides insight on how hypothetical building owners view flood proofing with different perspectives and priorities. These example case studies are not intended to cover the many possibilities for potential flood proofing of buildings located in the flood plains. However, they should be helpful in illustrating the numerous approaches toward evaluating flood proofing options.

FIGURE 2 — FLOOD PROOFING MATRIX

FLOOD PROOFING MATRIX

		FLOOD PROOFING MEASURES								
		Elevation on Foundation Walls	Elevation on Piers	Elevation on Posts or Columns	Elevation on Piles	Relocation	Floodwalls and Levees	Floodwalls and Levees with Closures	Dry Flood Proofing	Wet Flood Proofing
FLOODING CHARACTERISTICS	**Flood Depth**									
	Shallow (less than 3 feet)									
	Moderate (3 to 6 feet)								N/A	
	Deep (greater than 6 feet)						N/A	N/A	N/A	N/A
	Flood Velocity									
	Slow (less than 3 fps)									
	Moderate (3 to 5 fps)								N/A	N/A
	Fast (greater than 5 fps)	N/A[1]	N/A[1]				N/A[1]	N/A[1]	N/A	N/A
	Flash Flooding									
	Yes (less than 1 hour)	N/A[1]						N/A[2]	N/A[2]	N/A[2]
	No									
	Ice and Debris Flow									
	Yes	N/A						N/A	N/A	N/A
	No									
SITE CHARAC-TERISTICS	**Site Location**									
	Coastal Floodplain	N/A					N/A	N/A	N/A	N/A
	Riverine Floodplain									
	Soil Type									
	Permeable						N/A[3]	N/A[3]	N/A	
	Impermeable									
BUILDING CHARACTERISTICS	**Building Foundation**									
	Slab on Grade									
	Crawl Space									
	Basement		N/A	N/A	N/A				N/A	N/A[4]
	Building Construction									
	Concrete or Masonry				N/A[5]					
	Wood and Others				N/A[5]				N/A	N/A[4]
	Building Condition									
	Excellent to Good									
	Fair to Poor	N/A	N/A	N/A	N/A	N/A			N/A	N/A

Based on FEMA's Flood Proofing/Retrofitting Decision Matrix
See page 21 for instructions on use of Matrix

Instructions for

FIGURE 2—FLOOD PROOFING MATRIX

STEP 1 – Select the appropriate row for each of the nine characteristics that best reflect the flooding, site, and building characteristics.

STEP 2 – Circle the N/A (not applicable) boxes in the rows of characteristics selected.

STEP 3 – Examine each column representing the different flood proofing measures. If one or more N/A boxes are circled in a column representing a flood proofing measure, that alternative should be eliminated from consideration unless special features (as footnoted) are applied to overcome the N/A concern.

STEP 4 – Test the flood proofing measures that do not have circled N/A boxes for compliance with your community's flood plain management ordinance and building permit requirements.

STEP 5 – Flood proofing measures that would be in compliance with community requirements should now be further evaluated for economic, aesthetic, risk, and other considerations. A preferred measure should evolve from this evaluation.

STEP 6 – Obtain professional engineering and construction services for detailed design and implementation of the preferred flood proofing measure. Professional advice may rule out the preferred measure and an alternate measure will need to be selected.

N/A[1] : Fast flood velocity is conducive to erosion and special features include protective material to resist anticipated erosion.

N/A[2] : Flash flooding does not allow time for human intervention; thus, these measures must perform without human activity involved. Openings in foundation walls must be large enough to equalize water forces and should not have removable covers. Closures and shields must be permanently in place, and wet flood proofing cannot include last-minute modifications.

N/A[3] : Permeable soils allow seepage under floodwalls and levees; therefore, some type of cutoff feature would be needed beneath structures.

N/A[4] : Only selective features would be included that could wateproof individual items, relocate them above potential water levels, or avoid structural damage.

N/A[5] : The building must be temporarily relocated to place piles and complete foundation. If space is available this may be accomplished; however, additional expense will be involved.

REFERENCES

- *Design Manual For Retrofitting Flood-Prone Residential Structures, FEMA 114*
  Federal Emergency Management Agency
  Washington, D.C.
  September 1986

- *Flood Insurance Study, City of Englewood, Bergen County, New Jersey*
  Federal Emergency Management Agency
  Washington, D.C.
  February 19, 1986

- *Flood Proofing Non-Residential Structures, FEMA 102*
  Federal Emergency Management Agency
  Washington, D.C.
  May 1986

- *Flood Proofing Techniques, Programs, and References*
  U.S. Army Corps of Engineers, National Flood Proofing Committee
  Washington, D.C.
  February 1991

- *Means Building Construction Cost Data, 1993 (51st Annual Edition)*
  R.S. Means Company, Inc.
  Kingston, MA
  1992

- *Means Site Work & Landscape Cost Data, 1993 (12th Annual Edition)*
  R.S. Means Company, Inc.
  Kingston, MA
  1992

- *National Capital Section Achievement Award*
  Washington Harbour Flood Control Project
  (designed by Sverdrup Corporation)
  American Society of Civil Engineers
  Washington, D.C.
  March 1988

- *Raising and Moving The Slab-on-Grade House – With Slab Attached*
  U.S. Army Corps of Engineers, National Flood Proofing Committee
  Washington, D.C.
  February 1990

- *Repairing Your Flooded Home, FEMA 234*
  Federal Emergency Management Agency
  Washington, D.C.
  August 1992

APPENDIX A

HOW TO PERFORM A DETAILED EVALUATION OF FLOOD PROOFING OPTIONS

APPENDIX A

HOW TO PERFORM A DETAILED EVALUATION OF FLOOD PROOFING OPTIONS

To illustrate how a detailed evaluation of flood proofing options would be conducted, a hypothetical home is described in this appendix to illustrate the process. The home has been located on an existing flood insurance study map.

EVALUATION OF INDIVIDUAL FLOODING SITUATION

The homeowner began to assess his individual flooding situation by considering the factors discussed in Chapters Three and Four. He then began the evaluation process by using the flood proofing matrix on Figure 2, Chapter 5. From his investigation into his community's Flood Insurance Study (FIS), he determined the 100-year flood elevation affecting his home. He found that the first floor elevation of his home was five feet below the 100-year flood. Although he was aware that greater floods could occur (after noting the 500-year flood illustrated in the FIS), he concluded that such large floods were probably beyond the scope of flood proofing measures. Thus, his flood depth was established as moderate (3-6 feet).

He could find no specific records of past flow velocities of the stream. However, since he and his neighbors had not experienced problems with erosion during past storms, he assumed that his home and yard were not subject to fast floodwaters or flash floods. His home is not subject to ice and debris flow, and is located in a riverine flood plain on impermeable soils. His building is constructed of wood with a slab-on-grade foundation and is in excellent condition. Based on information in the decision matrix and the fact that he had limited space for floodwalls or levees, he decided to investigate options for elevating his home so that the first floor would be at the 100-year elevation. He wanted to stay in the same location, therefore, relocation was considered a last resort. Before inviting a professional engineer and a contractor to visit the site and provide designs and a cost estimate for elevating his home, he wanted to estimate how much he could spend on flood proofing and expect to recover in reduced flood damages.

ANALYSES OF BENEFITS AND COSTS

The evaluation process includes a detailed economic analysis of the potential benefits of flood proofing. The analysis requires some familiarity with economics, hydrology, and hydraulics; therefore, the average property owner would normally require the assistance of a water resource planner or engineer. This process includes obtaining flood hazard data for the flooding source and developing the relationships among flow (discharge), water-surface elevation, and flood frequency (probability) for the building site. These relationships are used in conjunction with estimates of potential flood damage (curves are provided in this appendix) to compute the average annual flood damages that could be prevented by flood proofing the building to a chosen level. This "average annual damage prevented" is the benefit the property owner would receive from flood proofing. The average annual damage prevented over the expected life of the building is then converted into a present worth value. This is the maximum amount that is economically justified for the owner to invest in flood proofing. However, as discussed in the main text of this document, economic analysis is one of many factors assessed in making flood proofing decisions. It may not be the prominent factor for many property owners.

The method for this economic analysis is based on assuming that future flooding events will occur in a manner similar to those in the past. Although future floods could be more or less severe and frequent than past flood events, historical storms are used to estimate future hydrologic relationships.

Flood Hazard Information

To perform an economic analysis, property owners need information on flood hazards affecting their buildings. One of the more widely available sources of this information is FISs, published by the Federal Emergency Management Agency (FEMA) for most flood-prone communities throughout the United States. The FIS should be available from the municipal engineering department or public works department responsible for flood plain management. If this information is not available from a community official, the property owner may call FEMA at 1-800-358-9616 to determine the availability of an FIS report for the community and how to obtain a copy. In this example, the property owner visited city hall and used the file copy of the FIS to obtain flood hazard information for his home.

What is in an FIS?

The FIS provides the property owner with important flood hazard data for the flooding source including discharges and corresponding water-surface elevations for a range of probability levels. Discharge—usually expressed in terms of cubic feet per second (cfs)—is the volume of water that will flow in a stream or river and over its banks during a given time. Through the statistical analysis of stream gaging data or from computer models of the drainage area runoff, discharges are computed at different points along the flooding source for various probabilities.

The discharge probability is expressed in terms of a flood frequency, such as the 100-year flood frequency. The flood frequency refers not to how often a certain discharge will occur but is a statistical tool used to define the probability that a certain discharge will be equaled or exceeded in any given year. This probability, which is normally referred to as the exceedance probability, is equal to 100 divided by the flood frequency. For example, the 100-year discharge has a one percent (100 divided by 100-year) chance of being equaled or exceeded in any given year. By using the discharges in conjunction with stream or river geometry and the principles of hydraulics, water-surface elevations can be computed along the stream for each discharge.

The relationships between discharges and water-surface elevations and between discharges and exceedance probabilities can be used to determine the probabilities of various flood levels inundating buildings. For most streams with significant flood hazards, the FIS normally contains discharges and water-surface elevations for the 10-, 50-, 100-, and 500-year floods, which have annual exceedance probabilities of 10%, 2%, 1%, and 0.2%, respectively. In our example, the homeowner found that the community's FIS did contain information on the 10-, 50-, 100-, and 500-year floods for his flooding source, providing him with the information he needed to complete the economic analysis.

Other Sources of Flood Plain Information

In some cases, the FIS may not be available for the property owner's community, or may not have sufficient data for the flooding source affecting the building. Other sources of data may be available. The U.S. Army Corps of Engineers (COE) and Soil Conservation Service (SCS) publish flood hazard information reports for many flooding sources. The U.S. Geological Survey (USGS) and the Tennessee Valley Authority (TVA) also publish stream gaging data and have flood information reports for various flooding sources. State or local flood plain studies may also be available for some communities. To perform an economic analysis, analysts need to know the relationship between discharge and water-surface elevation (often referred to as the rating curve) and the relationship between discharge and exceedance probability. For more information concerning available data, contact the flood plain management services office of the COE or the local offices of the USGS, TVA, or SCS. Guidance on how to obtain information is contained in Chapter Two.

DISCHARGES

The analyst should determine the discharges at the point along the flooding source (stream, river) near the building's location. Discharges are presented in a summary table in the FIS report. When discharges are listed for various locations on the stream, analysts should use the discharges listed for the closest location downstream from their building. In this example, the homeowner located the summary of discharges table in the community's FIS, as shown in Table A-1.

TABLE A-1 — SUMMARY OF DISCHARGES

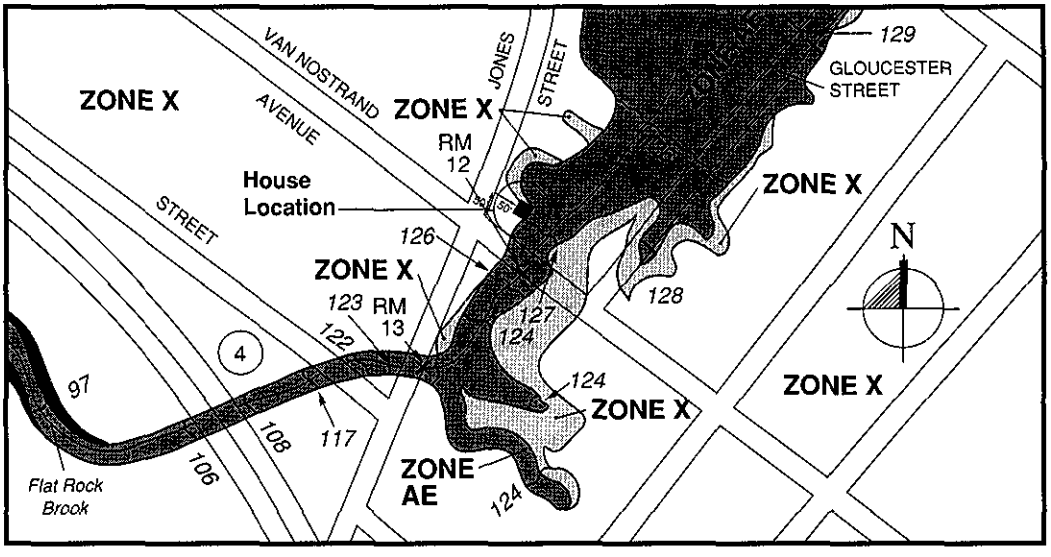
Flooding Source and Location	**Drainage Area**	**Peak Discharges (cfs)**			
	(square miles)	*10-Year*	*50-Year*	*100-Year*	*500-Year*
Overpeck Creek					
• Upstream of the confluence of Flat Rock Brook	8.1	910	1,310	1,490	1,960
• Upstream of the confluence of Tributary to Overpeck Creek	5.7	760	1,090	1,200	1,600
• Upstream of the confluence of Metzlers Creek	3.0	530	750	830	1,100
Tributary to Overpeck Creek					
• At its confluence with Overpeck Creek	1.0	275	445	545	810
Metzlers Creek					
• At its confluence with Overpeck Creek	2.4	453	625	704	995
Flat Rock Brook					
• At its confluence with Overpeck Creek	2.5	665	1,075	1,315	1,980

Since only one set of discharges is listed in the table for Flat Rock Brook (this owner's flooding source), he used these as the discharges for his analysis.

FLOOD INSURANCE RATE MAP (FIRM)

For FISs, flood plains are delineated on the FIRM. The flood plain is the area that would be inundated by flood discharges for a certain frequency flood. For most FIRMs, flood plains are delineated for floods of 100- and 500-year frequencies. Figure A-1 shows the portion of the community's FIRM where the home in this example is located.

FIGURE A-1 — HOUSE LOCATION ON THE FIRM



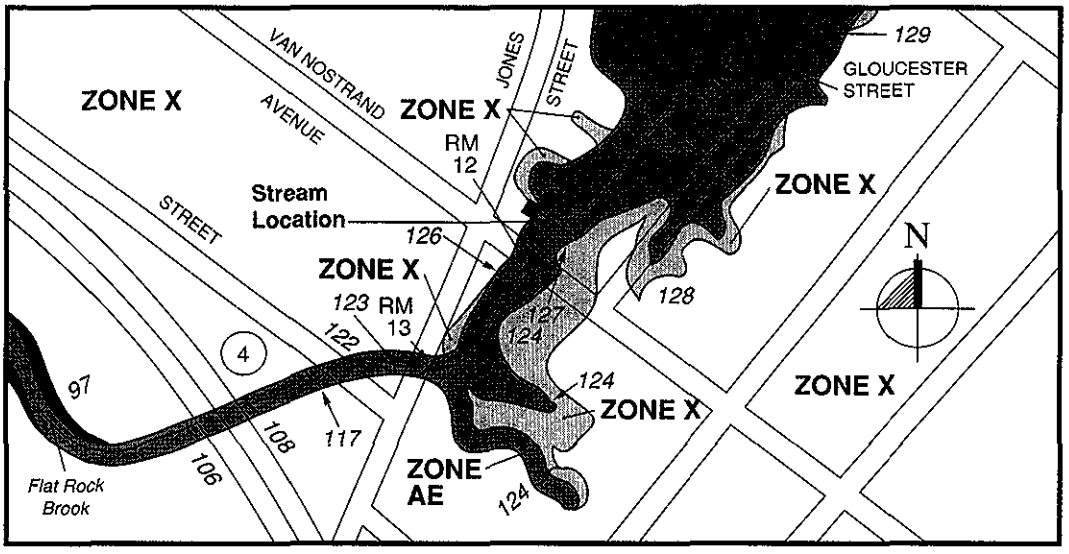
The homeowner approximated the location of his home by pacing off the distance from the intersection of Van Nostrand Avenue and Jones Street. He found that his house was located approximately 50 feet from the east side of Jones Street about 50 feet north of the intersection. He then measured these distances on the FIRM *(Figure A-1)*. The map's scale was one inch equals 400 feet. Therefore, on the FIRM he measured 0.125 inches (50 feet divided by 400 feet per inch) along Jones Street from its intersection with Van Nostrand Avenue and 0.125 inches from Jones Street, marking this point as the location of his house. *(Figures A-1, A-2, and A-3 are not at original scale)*

The darker shaded area on the map is the 100-year flood plain. The lighter shaded area denotes the 500-year flood plain. The house is located in this area between two wavy lines numbered 127 and 128. These are the 100-year flood elevations at those stream locations. Therefore, the homeowner knew the 100-year flood elevation affecting his home was between 127 and 128 feet. Flood elevations for the other frequencies are shown on the stream's water-surface profile in the FIS report.

FLOOD PROFILE

FIS reports have flood profiles depicting flood elevations along each stream for the various frequencies. For the example, the property owner determined the position of his home on Flat Rock Brook by drawing a line on the FIRM *(Figure A-2)* through the location of his home and perpendicular to the stream. The point where this line crosses the streamline is the location of his home along the stream.

FIGURE A-2 — STREAM LOCATION ON THE FIRM



He measured the distance along the stream *(Figure A-2)* from the location of his home to Van Nostrand Avenue, the nearest bridge structure across Flat Rock Brook. He found this distance to be 0.11 inches, a measurement that when converted to the map scale, is equal to approximately 45 feet (0.11 inches multiplied by 400 feet per inch of map). He located the Van Nostrand Avenue bridge on the Flat Rock Brook profile *(Figure A-3)*. He measured 0.45 inches upstream of the Van Nostrand Avenue bridge (45 divided by 100 feet per inch which is the horizontal scale of the profile). He marked this location as the point on Flat Rock Brook with water surface elevations equivalent to his home. He read the elevations on the profile at this point and obtained elevations of 124.5, 125.9, 127.1, and 128.1 feet for the 10-, 50-, 100-, and 500-year floods, respectively. He also noted that the bottom of the Flat Rock Brook channel shown on the profile was located at an elevation of 119.5 feet.

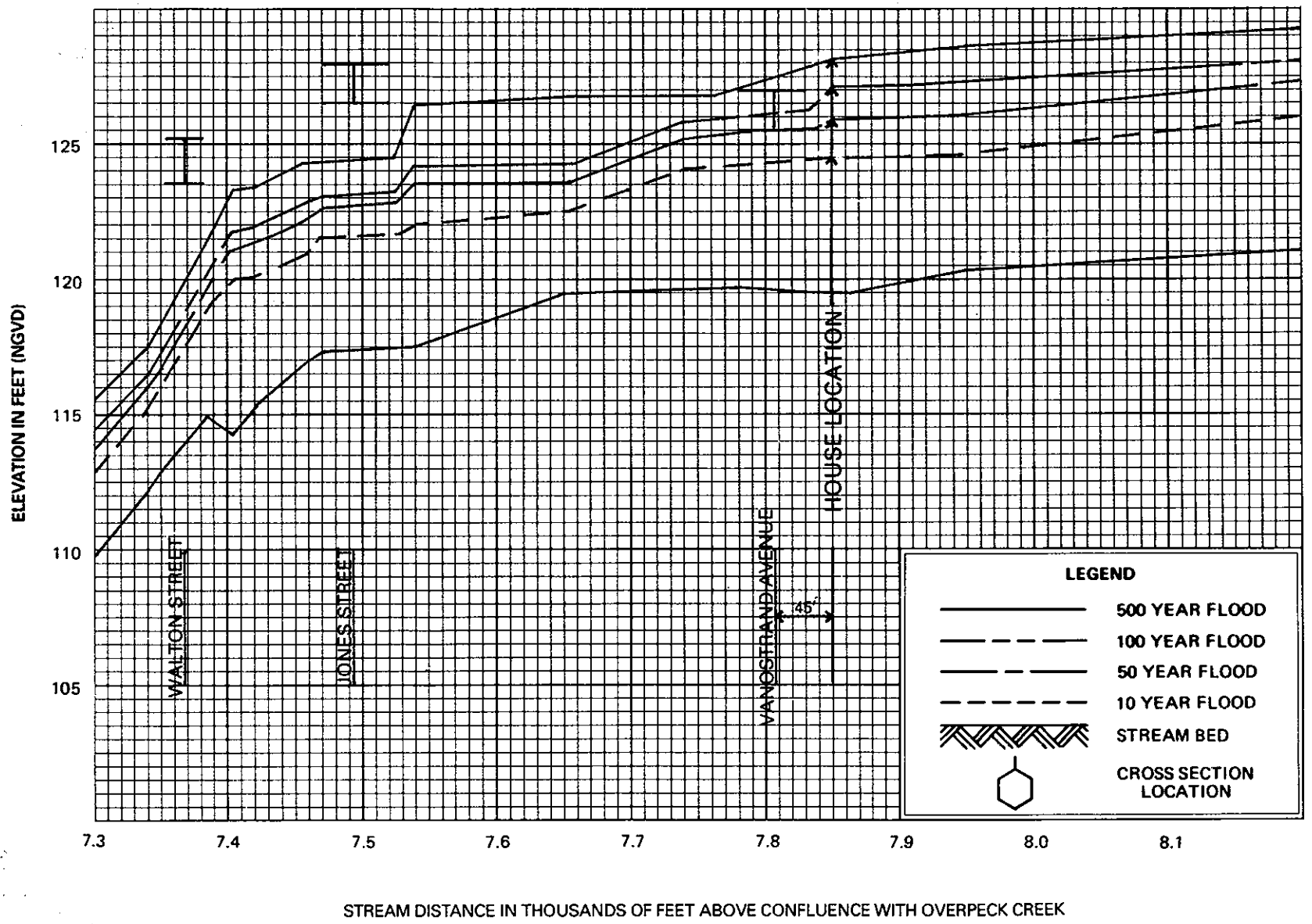


FIGURE A-3 — HOUSE LOCATION ON FLOOD PROFILE FOR FLAT ROCK BROOK

Flood Data Summary

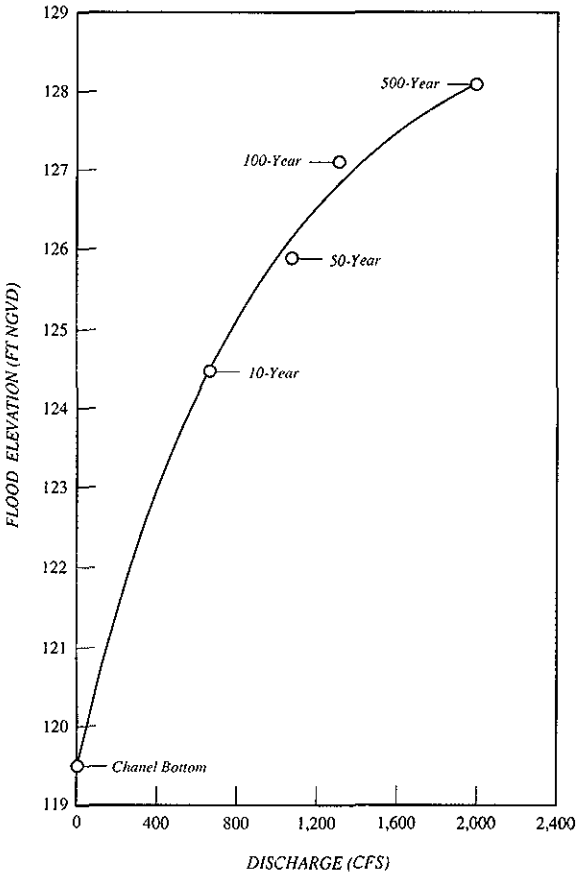
Table A-2 summarizes the flood data obtained from the FIS for the example analysis.

Table A-2 — Flood Data Summary

Frequency	Exceedance Probability	Discharge	Elevation
Channel Bottom	---	0 cfs	119.5 feet
10-year	10.0%	665 cfs	124.5 feet
50-year	2.0%	1,075 cfs	125.9 feet
100-year	1.0%	1,315 cfs	127.1 feet
500-year	0.2%	1,980 cfs	128.1 feet

Exceedance probabilities were calculated by dividing 100 by the frequency. An entry was also made for the bottom of the channel elevation, which represents a condition of no discharge. An exceedance probability is not computed for the channel bottom because that point is used only to construct the discharge versus elevation curve.

Figure A-4
Discharge Versus Elevation (Rating Curve)



Discharge Versus Elevation Curve (Rating Curve)

After accomplishing the above tasks, it was time to graph the relationships between exceedance probability, discharge, and water-surface elevations at the home. The first graph developed is the relationship between discharge and water-surface elevation. For each discharge in the summary table, a point is plotted for the discharge and the corresponding water-surface elevation. After plotting all of the points, a smooth curve is sketched through the points to obtain the rating curve shown on Figure A-4.

Discharge Versus Exceedance Probability Curve

Next, the relationship between discharge and exceedance probability is plotted in a similar manner on probability paper. Figure A-5 *(next page)* shows the type of probability paper used. The vertical axis represents the discharge values. However, the ordinates are not spaced linearly. Rather, they are spaced in two logarithmic cycles, each numbered from one to nine. The numerical values assigned to the vertical axis are based on the range of discharges being considered for the example—a range between 665 cfs and 1,980 cfs. *(See Table A-2)* Therefore, the ordinates on the lower cycle were assigned values from 100 to 1000, while the ordinates in the top cycle were assigned values from 1,000 to 10,000. Thus, the entire range of discharges being considered can be graphed. If the discharges being considered had been from 25 to 150 cfs, the ordinates on the lower cycle would have been assigned values from 10 to 100 and the ordinates on the top cycle would have been assigned values from 100 to 1,000.

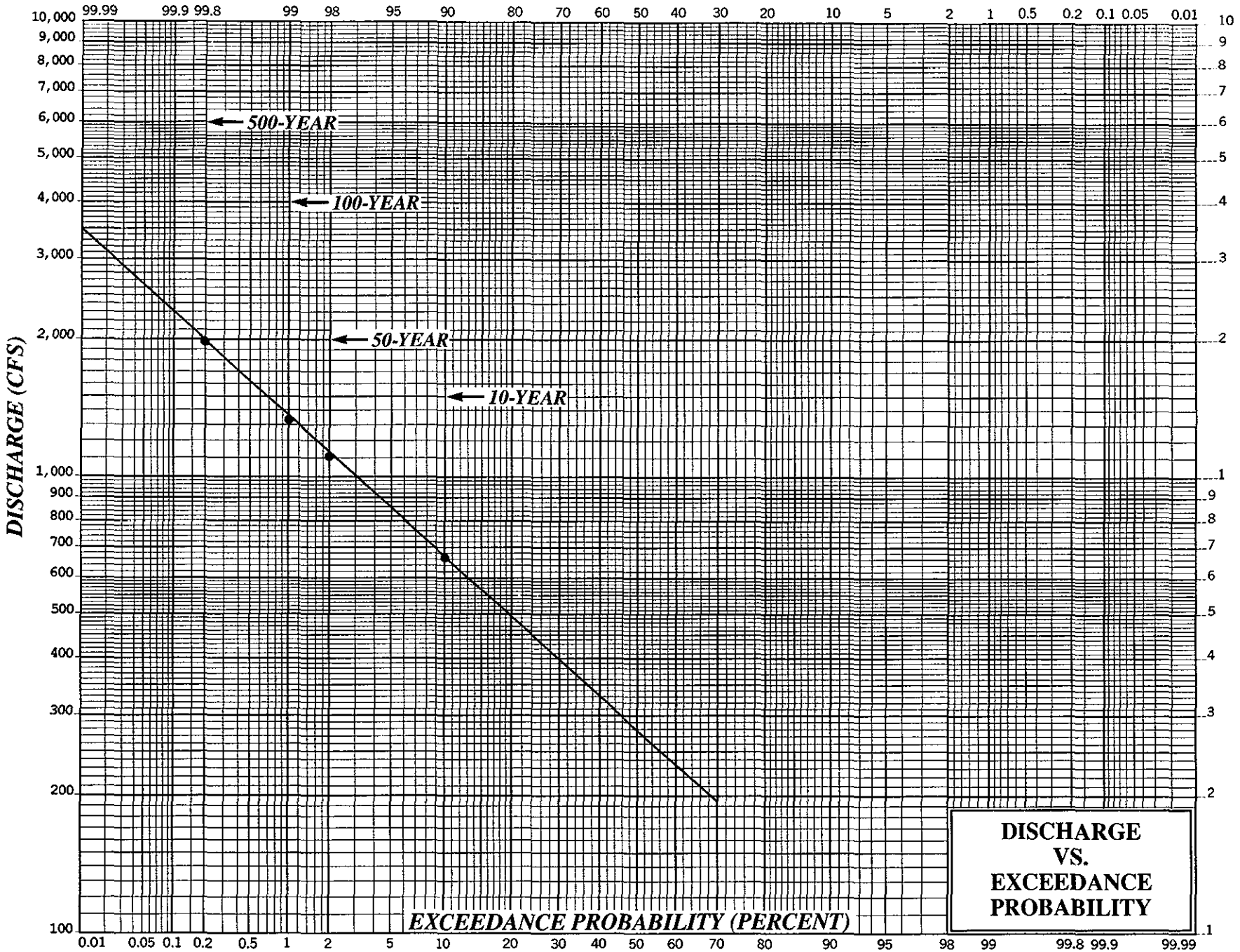


FIGURE A-5 — DISCHARGE VERSUS EXCEEDANCE PROBABILITY

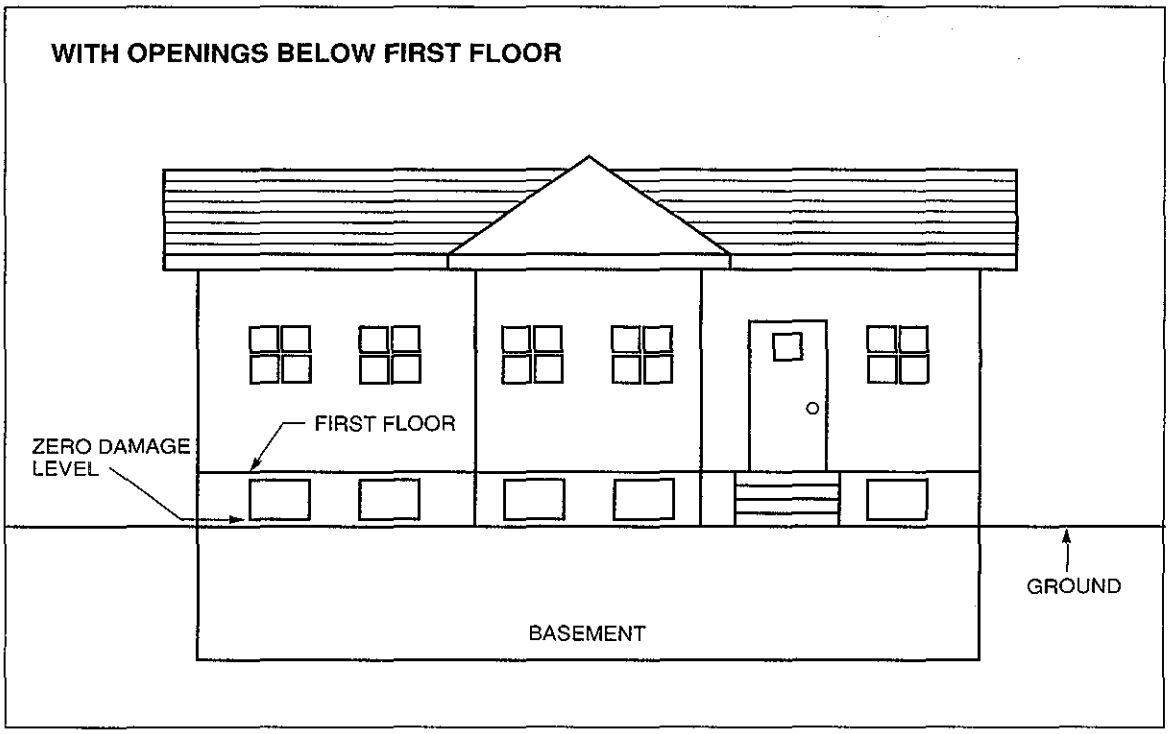
The horizontal axis represents exceedance probabilities. As discussed previously, the ten-year flood has a 10% chance of being equaled or exceeded in any given year. Therefore, a point for the ten-year discharge is plotted at 665 cfs on the vertical axis and 10% on the horizontal axis. This process is then repeated for the discharges and probabilities of floods for the 50-, 100-, and 500-year floods. After all data points are plotted, a line is drawn through the points. For the example, the resulting discharge versus exceedance probability curve is shown in Figure A-5.

ZERO-DAMAGE LEVEL

The next step is to determine the elevation at which flooding begins to damage the home and its contents, referred to as the zero-damage level. This elevation will be at various levels, depending on the type of building being evaluated. Flood levels below the zero-damage elevation of the building may cause some damage to the yard and landscaping. If the building is not structurally sound, water pressure could cause damage prior to entering the building. However, such damage is not evaluated in the example.

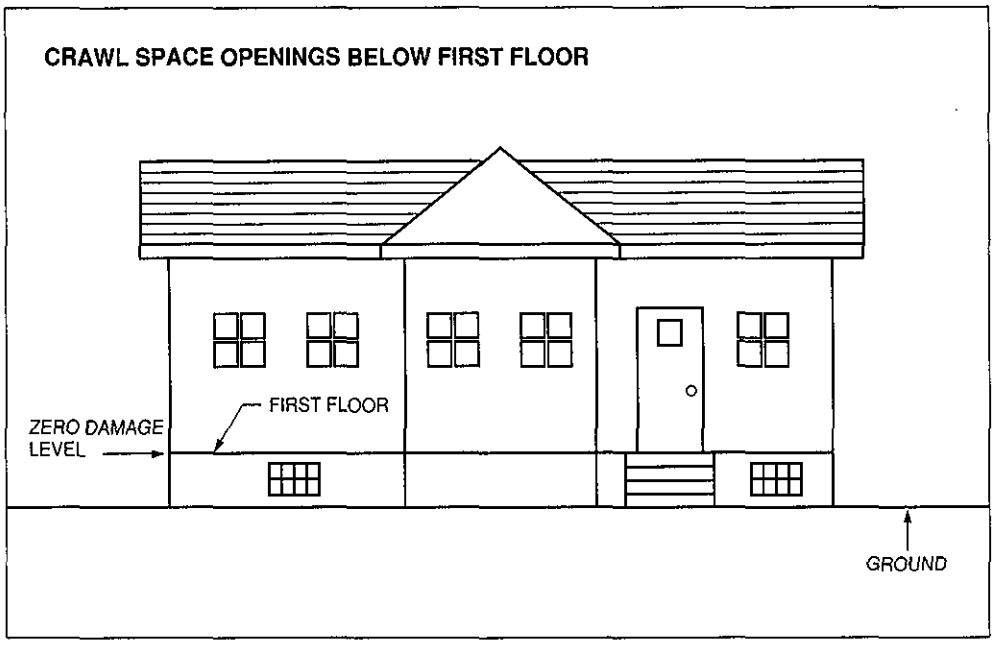
For buildings with openings below the first floor, such as basements with windows or doors, the zero-damage level *(Figures A-6 and A-8)* would be located at the lowest elevation that will allow floodwaters to enter the openings and damage appliances, utilities, and other items located in the basement.

FIGURE A-6 — ZERO-DAMAGE LEVEL FOR BUILDING WITH OPENINGS BELOW FIRST FLOOR



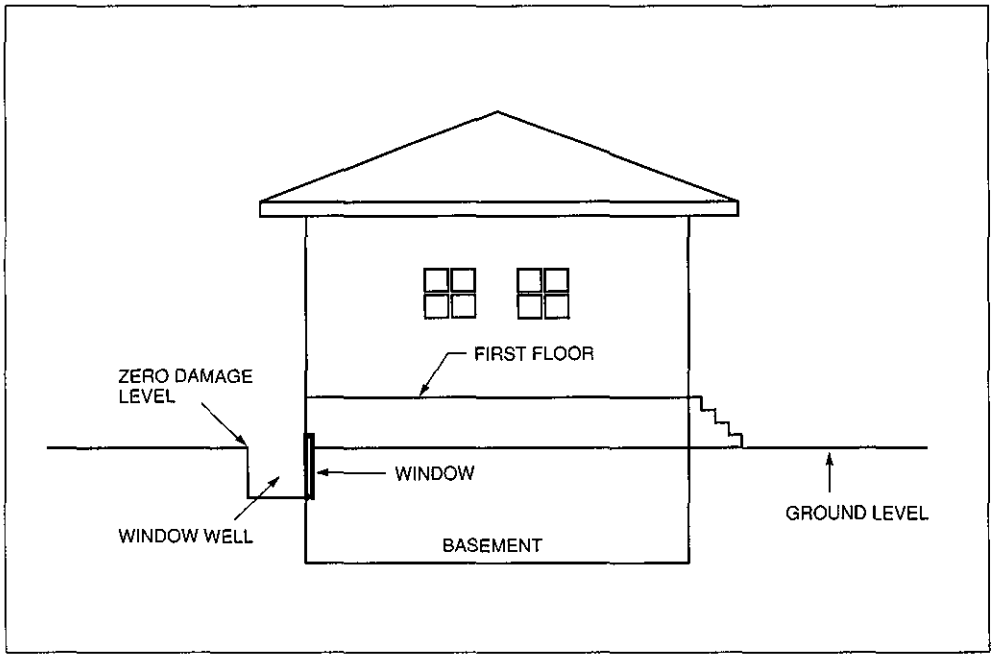
For buildings with no openings below the first floor, such as slab-on-grade construction, the zero-damage level would be located at the bottom of the first floor level. At this level, floodwaters would be able to enter through the doorway opening.

FIGURE A-7 — ZERO-DAMAGE LEVEL FOR BUILDING WITH CRAWL SPACE OPENINGS BELOW FIRST FLOOR



For other types of buildings, the general rule-of-thumb in determining the zero-damage flood level is to locate the highest elevation or depth that floodwaters must rise to before entering the building and causing damage. For example, if floodwaters enter the crawl space in Figure A-7, only minor damage would occur because water forces on the walls would be equalized. The zero-damage level for a home with window wells in the basement would be the elevation at the top of the window well rather than the bottom, provided there are no other places in the structure that will allow floodwaters to enter first. Although the bottom of the window is lower, the water must rise to the top of the well to enter the opening. In sandy soils, however, water may enter the window well from groundwater flow, if the window well is not watertight. The zero damage level would then be the bottom of the window. Figure A-8 illustrates window well conditions.

FIGURE A-8 — ZERO-DAMAGE LEVEL FOR BUILDING WITH WINDOW WELLS



The zero damage levels illustrated are based on the assumption that foundations and other supporting material below the top of the first floor are resistent to flood damages. Actual damage claims received by the Federal Insurance Administration indicate that this assumption is generally not the case in most flood events. In some cases, highly permeable soils around the structure and/or walls below ground that have been improperly sealed may allow groundwater to seep through the walls in considerable quantities before surface floodwaters reach the level of the lowest opening on the structure or damage may ocur to the substructure of the building.

Determine the First Floor Elevation

The determination of first floor elevation can be made in a number of ways. The most accurate way is to hire a professional land surveyor to field-measure the first floor elevation from a local surveying benchmark or other point of known elevation. Other less accurate methods include measuring (such as with a hand level) from a nearby benchmark, a neighbor's property that has been surveyed, or any other point of known elevation. Also, property owners who have experienced prior flooding may have marked the water level on the building. These property owners can check local flood records for the elevation of the flooding source during that storm and estimate the first-floor elevation relative to their highwater mark. The level of accuracy and extent of cost to determine the first-floor level should be based on the expenditure the property owner might consider making for flood proofing. A larger amount invested in flood proofing would justify a greater degree of accuracy in determining the first-floor elevation.

For this example, the homeowner hired a friend who was a professional land surveyor to determine the first floor elevation of his home. Using a nearby surveying benchmark as a reference point, they determined the first floor elevation to be 122.1 feet National Geodetic Vertical Datum (NGVD 29). Future elevations will be based on the National Adjusted Vertical Datum (NAVD 88).

Depth Versus Damage Data

To estimate monetary damages to buildings for various flood depths, use the accompanying depth versus damage curves. These curves depict the relationship between flood depths and damage expressed as a percentage of the value of the building, with the zero-foot flood depth representing the top of the finished flooring of the lowest floor above any basement. Figures A-9 through A-12 relate flood depths to structural damage for a mobile home without basement, a one-story home without basement, a one-story home with basement, a split level home without basement, a split level home with basement, and a two-story home with and without basement, respectively. Figures A-13 and A-14 relate flood depths to home contents damage for a mobile home, a single-floor home (no basement), and a multi-floor home (basements are included as a floor). Contents damage includes damage to all furniture, small appliances, clothing, and other incidental items not included in building value. Figures A-9 through A-12 do not cover all types of buildings but do represent the most common residential structures. For other types of buildings, depth versus damage data may be available from another source or adjustments can be made to the provided curves to fit a particular building. The damage data in Figures A-9 through A-14 are shown as percentages of the total value of the building or its total contents depending on which curves are being used. For this analysis, the value of the building may be determined from tax assessments if they reflect market value or from a contractor's estimate of building replacement. The value of contents can be an estimate of replacement cost (which includes depreciation) of all of the building's contents or an average percentage of the value of the building, which has been estimated by insurance companies to be approximately 50 percent. However, to obtain the prevailing rates in the local community, contact insurance companies providing flood insurance. Note that on Figure A-14 the "First Floor Only" has higher percentages than the "First Floor and Above" because the multiple-floor structures are more expensive.

FIGURE A-9 — DEPTH VERSUS DAMAGE FOR A MOBILE HOME WITHOUT BASEMENT

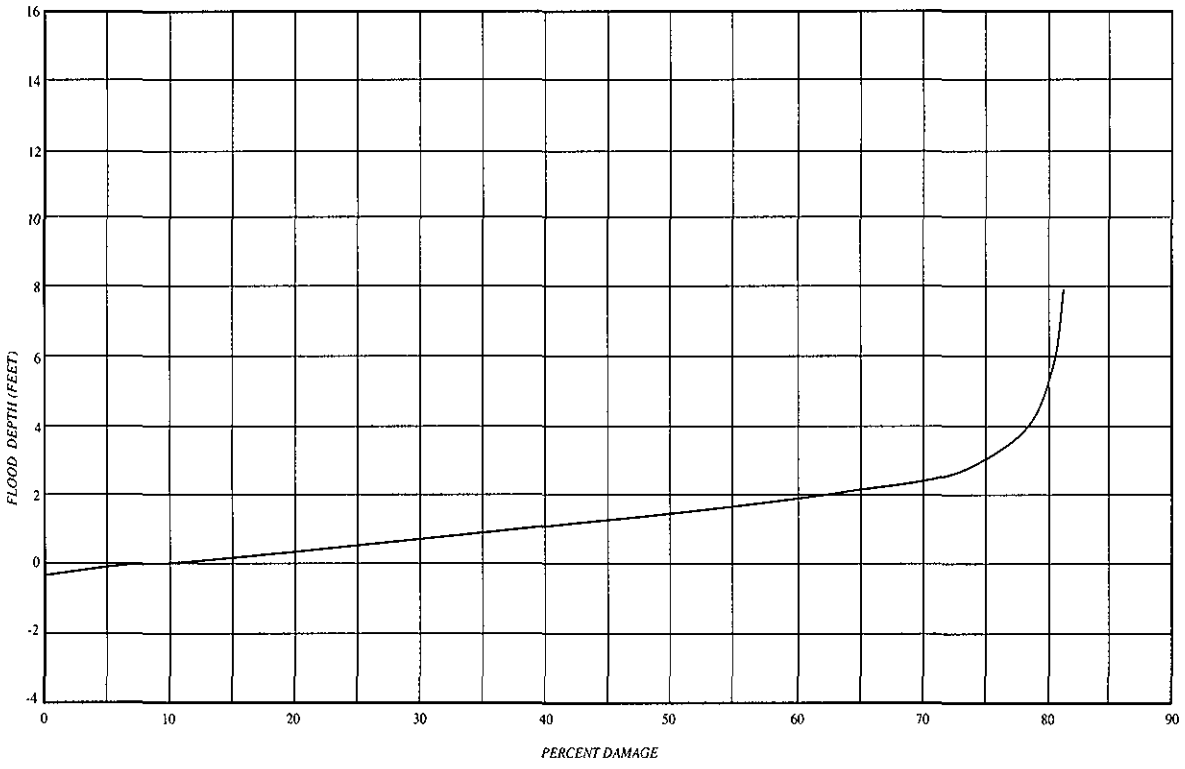
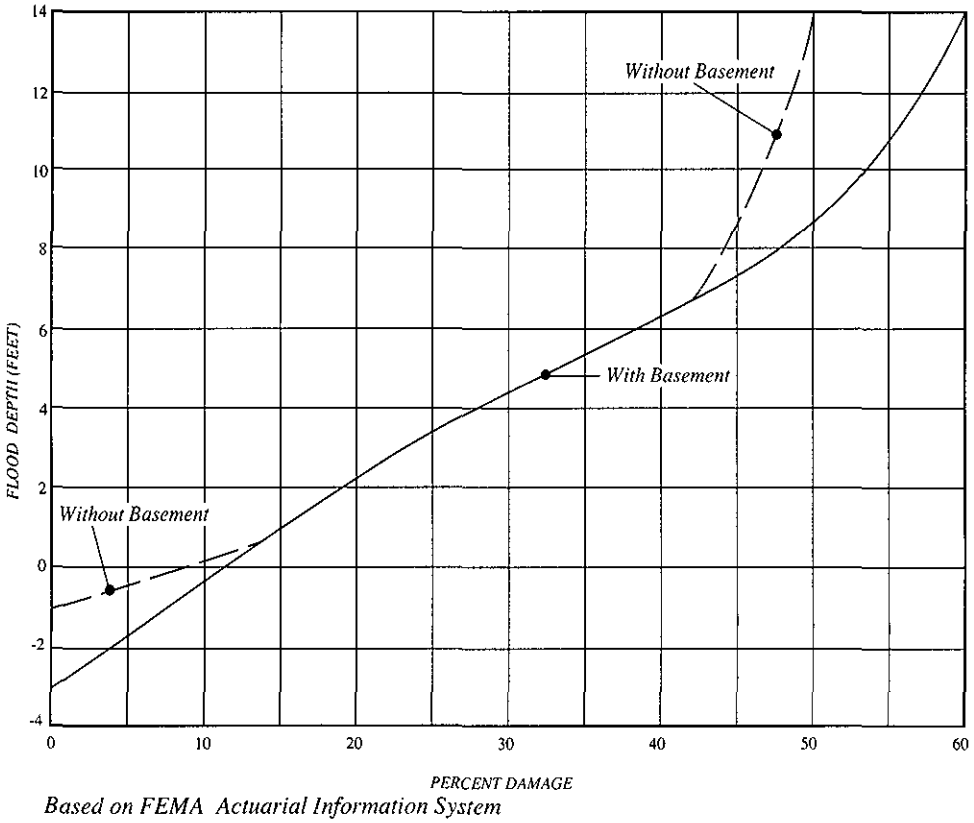


FIGURE A-10 — DEPTH VERSUS DAMAGE FOR A ONE-STORY HOME



Based on FEMA Actuarial Information System

FIGURE A-11 — DEPTH VERSUS DAMAGE FOR A SPLIT-LEVEL HOME

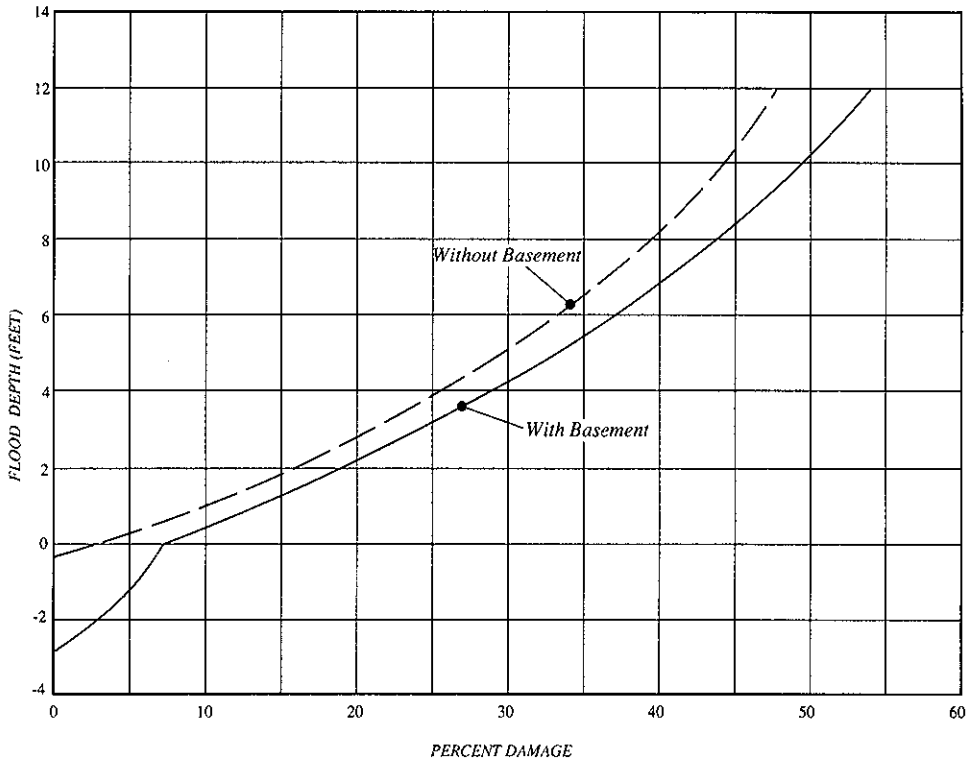
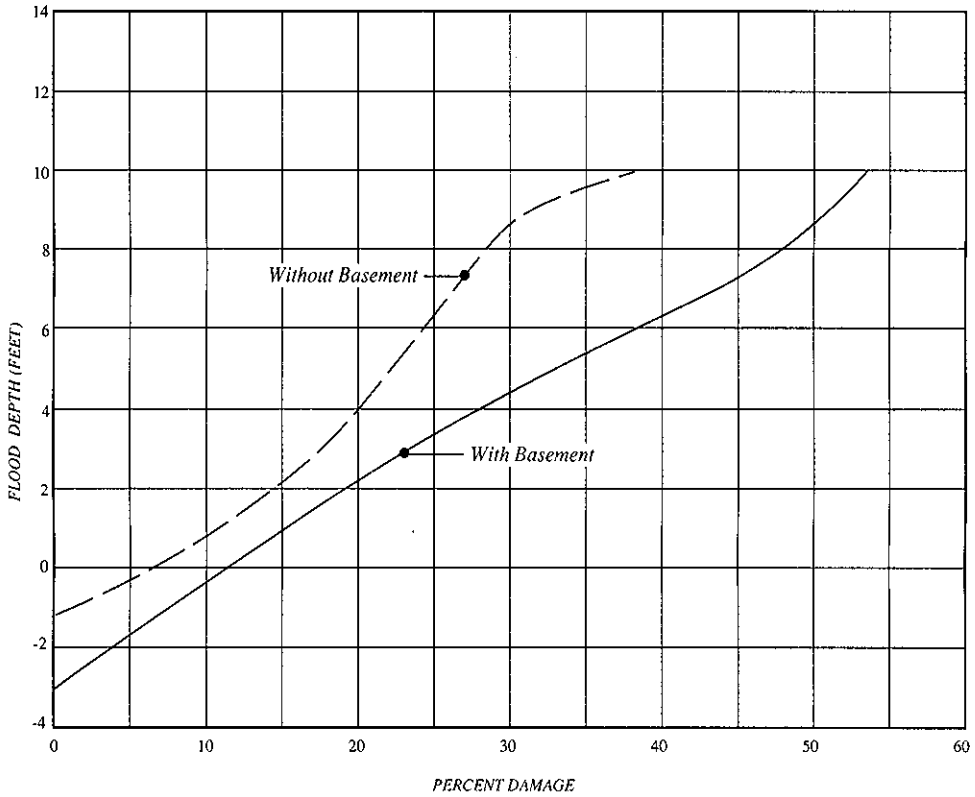


FIGURE A-12 — DEPTH VERSUS DAMAGE FOR A TWO-STORY HOME



Based on FEMA Actuarial Information System

FIGURE A-13 — DEPTH VERSUS DAMAGE FOR MOBILE HOME CONTENTS

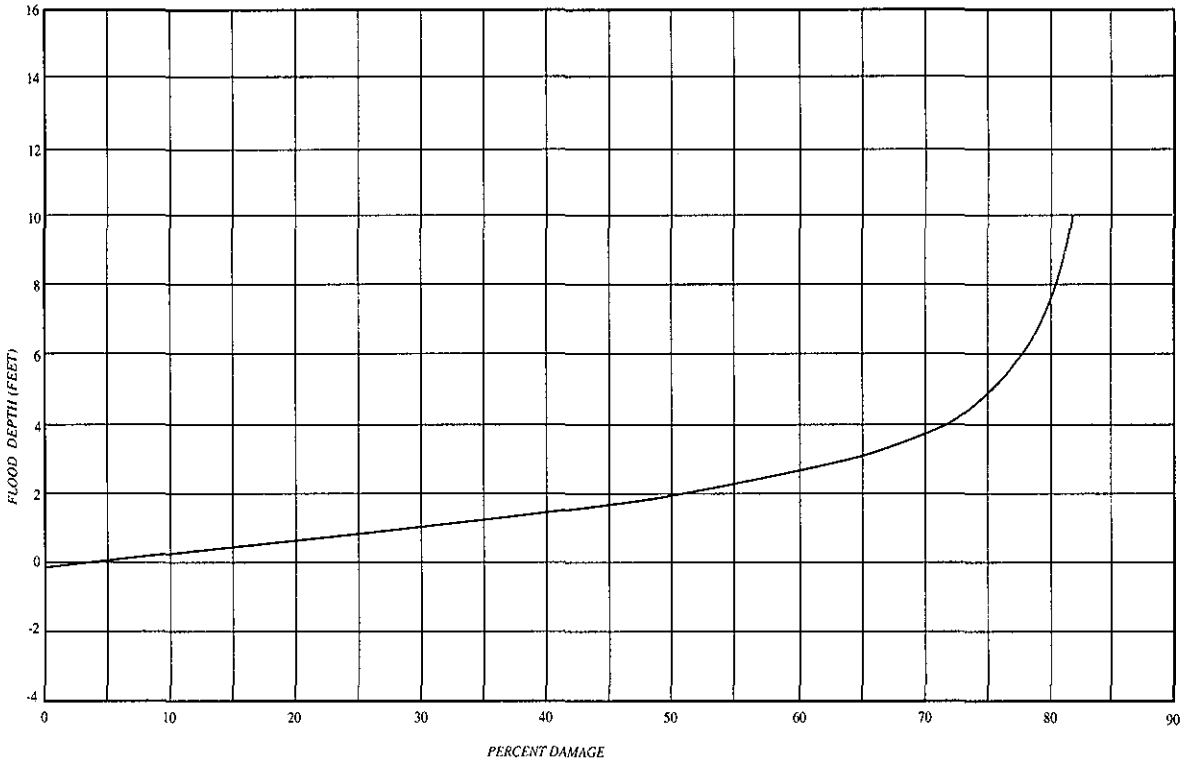
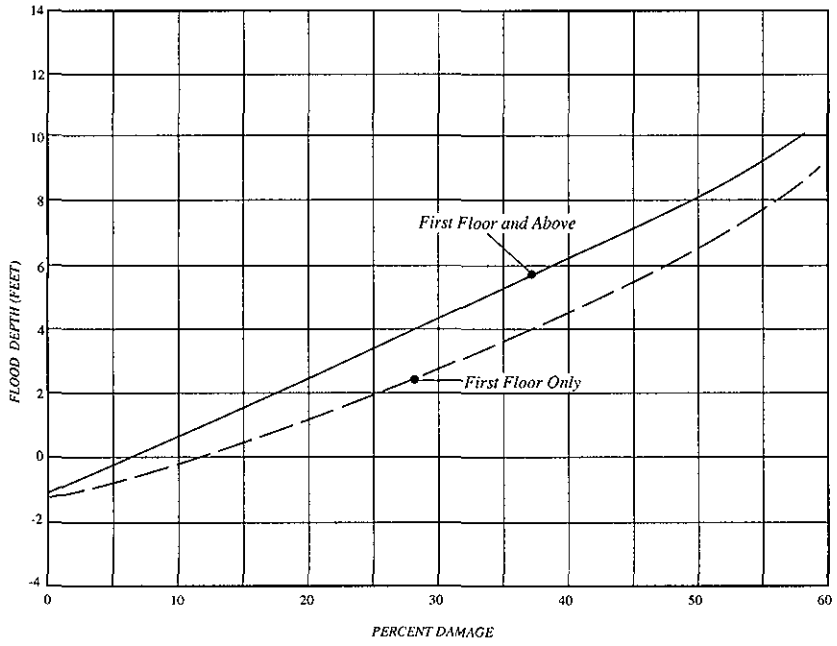


FIGURE A-14 — DEPTH VERSUS DAMAGE FOR HOME CONTENTS



Based on FEMA Actuarial Information System

These depth versus damage curves are based on statistical analyses of flood insurance claims data by the Federal Insurance Administration. Property owners should realize that, since these are average values, their homes could receive more or less damage for these flooding depths depending on the value of the house and its contents. Property owners who have experienced past flooding may wish to develop their own depth-damage data based on their own damage repair costs from past flooding. Nearby COE and/or FEMA offices may have regional or local damage relationships. Commercial buildings and townhouses are not covered by the provided graphs; however, the NFIP Actuarial Information System located at FEMA Headquarters in Washington, D.C. has some of this type data.

The content and building damages do not include loss of income or the individual costs of food, lodging, and transportation during the flood and the rehabilitation period following the flood. These could be substantial and should be considered in any economic analysis.

For this example, Figure A-10 for a one-story building without basement was used to determine building damage. Figure A-14 is for a single floor building and was used to determine contents damage. The typical damage curves were adjusted in the example because experience with previous floods indicated that no flood damage occurred until the flooding reached the first floor level. In other cases the zero damage may also need to be adjusted, if flood experience with an actual building has established the correct zero damage level for that building.

Starting with the zero flood depth (the zero damage level in this example), a percent damage value was read from the building damage curve (Figure A-10) for each increment representing one-foot of depth. This procedure was then repeated for the contents damage curve (Figure A-14).

The percent damages to the building and contents were converted to dollar values. The latest tax assessment for this home indicated the value of the building as $75,000 and the land value as $25,000 for a total assessed value of $100,000. However, information provided by a local realtor indicated that similar property in the same community sold for an average of $120,000. From the tax assessment, it was determined that the value of the building was 75 percent of the total assessed value. Thus, the market value of the property ($120,000) was multiplied by 75 percent to determine a fair market value of $90,000 for the building. For the contents, based on the types and quality of furniture, appliances, and other contents, a value of 50 percent ($45,000) of the fair market value of the building was selected. Next, these dollar values for building damage and contents damage were multiplied by the percentage for building damage and contents damage, respectively, at each one-foot increment. The dollar values for building and contents damage were then added together to get the total damage at each one-foot increment.

Then, the flood depths were converted into elevations based on the first floor elevation. In this example, the flood elevations were determined by adding the flood depths to 122.1 feet NGVD (the first floor elevation). Next, a discharge was found for each elevation from the discharge versus elevation curve (Figure A-4). Then the exceedance probability for each discharge was determined from the discharge versus probability curve (Figure A-5). Table A-3 shows the results.

TABLE A-3 — DEPTH-DAMAGE DATA FOR EXAMPLE HOME

Depth *feet*	**Building Damage** $	**Contents Damage** $	**Total Damage** $	**Elevation** *feet, NGVD*	**Discharge** *cfs*	**Exceedance Probability** %
0.0	0	0	0	122.1	280	50.0
1.0	13,500	8,100	21,600	123.1	400	30.0
2.0	17,100	11,700	28,800	124.1	560	15.0
3.0	20,700	14,400	35,100	125.1	780	6.5
4.0	25,200	17,100	42,300	126.1	1,100	2.2
5.0	29,700	18,900	48,600	127.1	1,315	1.0
6.0	34,200	21,150	55,350	128.1	1,980	0.2
7.0	38,700	23,400	62,100	129.1	---	---

A discharge and probability could not be determined for the 129.1 foot elevation and above because this point is beyond the 500-year discharge—the limit of the rating curve.

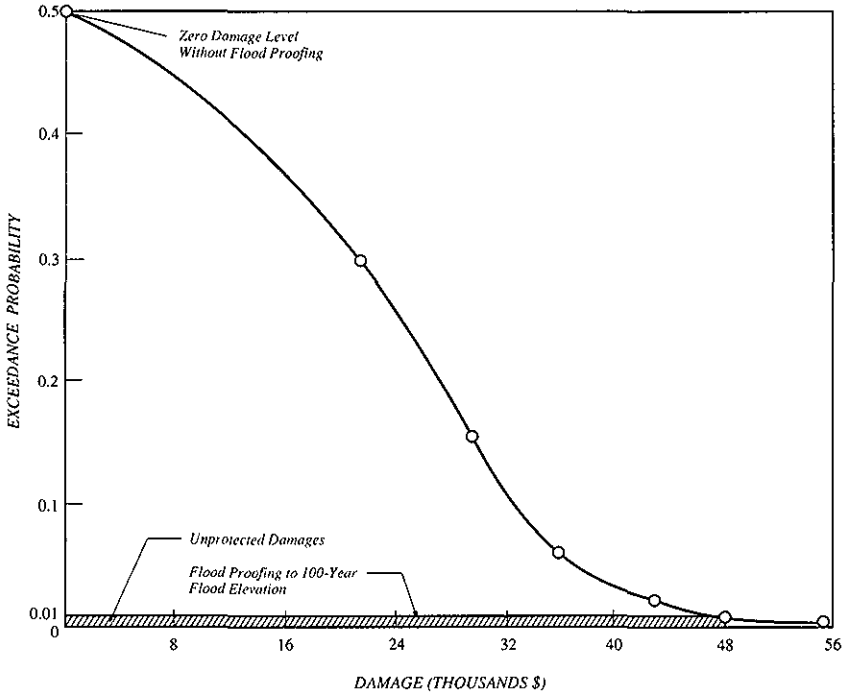
PROBABILITY VERSUS DAMAGE CURVE

The relationship between exceedance probability and damage for the home was plotted. The probability is expressed on the graph as a fraction of 100 percent. For example, 48 percent is expressed as .48 (48 percent divided by 100). For each probability in this table, a point for the probability and the corresponding damage was plotted and a smooth curve sketched through the points, as shown in Figure A-15. The area underneath this curve represents the average annual damage caused to the home by flooding.

BENEFITS OF FLOOD PROOFING

The benefit from flood proofing to a property owner is the prevention of damages that otherwise would have occurred without flood proofing. By flood proofing the building to a certain level, the property owner raises the zero-damage level, meaning that floodwaters will have to rise higher, above the flood proofing level, to damage the building. Annual average damage prevented by flood proofing can be determined by first drawing a horizontal line on the probability versus damage curve at the desired level of flood proofing. This line will represent the new zero-damage level after flood proofing. Then, the area undernearth the probability versus damage curve but above the new zero-damage level is calculated. This area represents the annual average damage prevented by flood proofing.

FIGURE A-15 — PROBABILITY VERSUS DAMAGE FOR EXAMPLE HOME



For this example, the property owner chose to flood proof to the 100-year flood level, which has a probability of 1 percent (100 divided by 100-year). Therefore, a horizontal line was drawn on the probability versus damage curve at the 0.01 (1 percent divided by 100) level. This line represents the new zero-damage level with flood proofing. The damage that could be prevented by flood proofing the home to the 100-year flood level is represented by the area above the new zero-damage level with flood proofing and underneath the probability versus damage curve. This area was calculated in the following manner:

- Beginning with the zero-damage level without flood proofing, a probability and damage were selected from the probability versus damage curve (.50, $0).

- Next, a lower point on the vertical axis of the probability versus damage curve was selected and recorded (.40, $15,000).

- The interval between the two probability levels was calculated (.50-.40 = .10).

- The average damage between the two probability levels was calculated ($0 + $15,000 ÷ 2 = $7,500).

- The probability interval and the average damage were multiplied (.10 x $7,500 = $750). This product represents the average annual damage prevented between these two probability levels.

- The above steps were repeated for probability levels at lower increments until the desired flood proofing level of .01 probability was reached.

- The incremental annual average damages were added to get the total annual average damage prevented by flood proofing.

These computations are shown in Table A-4.

TABLE A-4 — FLOOD DAMAGE PREVENTED

Probability	Damage	Probability Interval	Average Damage	Incremental Average Annual Damage Prevented
.50	$ 0			
		.10	$ 7,500	$ 750
.40	15,000			
		.10	18,300	1,830
.30	21,600			
		.10	23,800	2,380
.20	26,000			
		.10	29,250	2,925
.10	32,500			
		.09	40,550	3,650
.01	48,600			
				TOTAL= **$11,535**

From this analysis, it was determined that by flood proofing to the 100-year flood level an average of $11,535 in flood damages could be prevented per year.

After determining the average annual damage to be prevented by flood proofing, the present worth of damages prevented over the expected life of the structure can be determined. To make this determination, one must first assume the building's life expectancy; this will normally be the period the homeowner plans to occupy the home or the length of the mortgage. Second, an interest rate for borrowing money to flood proof must be assumed. This rate may be obtained from any bank. The property owner can then use Table A-5 *(next page)* to obtain a present worth factor for the assumed life of the structure and interest rate.

For interest rates and/or life of structure not provided in Table A-5, the present worth factor can be obtained by the following formula:

$$\text{Present Worth Factor} = \frac{(1+i)^n - 1}{i\,(1+i)^n}$$

n = *assumed life of structure*

i = *assumed interest rate for borrowing money*

Multiply the average annual damage prevented by flood proofing by the present worth factor to determine the present-day value of these expected flood damages.

TABLE A-5 — PRESENT WORTH FACTORS

Life of Structure *years*	ASSUMED INTEREST RATE 7%	8%	9%	10%	11%	12%
1	.9346	.9259	.9174	.9091	.9009	.8929
2	1.8080	1.7833	1.7591	1.7355	1.7125	1.6901
3	2.6243	2.5771	2.5313	2.4869	2.4437	2.4018
4	3.3872	3.3121	3.2397	3.1699	3.1024	3.0373
5	4.1002	3.9927	3.8897	3.7908	3.6959	3.6048
6	4.7665	4.6229	4.4859	4.3553	4.2305	4.1114
7	5.3893	5.2064	5.0330	4.8684	4.7122	4.5638
8	5.9713	5.7466	5.5348	5.3349	5.1461	4.9676
9	6.5152	6.2469	5.9952	5.7590	5.5370	5.3282
10	7.0236	6.7101	6.4177	6.1446	5.8892	5.6502
11	7.4987	7.1390	6.8052	6.4951	6.2065	5.9377
12	7.9427	7.5361	7.1607	6.8137	6.4234	6.1944
13	8.3577	7.9038	7.4869	7.1034	6.7499	6.4235
14	8.7455	8.2442	7.7862	7.3667	6.9818	6.6282
15	9.1079	8.5595	8.0607	7.6061	7.1909	6.8109
16	9.4466	8.8514	8.3126	7.8237	7.3792	6.9740
17	9.7632	9.1216	8.5436	8.0216	7.5488	7.1196
18	10.0591	9.3719	8.7556	8.2014	7.7016	7.2497
19	10.3356	9.6036	8.9501	8.3649	7.8393	7.3658
20	10.5940	9.8181	9.1285	8.5136	7.9633	7.4694
21	10.8355	10.0168	9.2922	8.6487	8.0751	7.5620
22	11.0612	10.2007	9.4424	8.7715	8.1757	7.6446
23	11.2722	10.3711	9.5802	8.8832	8.2664	7.7184
24	11.4693	10.5288	9.7066	8.9847	8.3481	7.7843
25	11.6536	10.6748	9.8226	9.0770	8.4217	7.8431
26	11.8258	10.8100	9.9290	9.1609	8.4881	7.8957
27	11.9867	10.9352	10.0266	9.2372	8.5478	7.9426
28	12.1371	11.0511	10.1161	9.3066	8.6016	7.9844
29	12.2777	11.1584	10.1983	9.3696	8.6501	8.0218
30	12.4090	11.2578	10.2737	9.4269	8.6938	8.0552

In this example, the life of the home was assumed to be 30 years along with an interest rate of 10 percent for borrowing money for flood proofing. From Table A-5, a present worth factor of 9.4269 was obtained. Multiplying this factor by average annual damages of $11,535 prevented by flood proofing, a present-day worth of $108,700 for damage prevented over the life of the home was computed. If future flood events occurred like past ones, flood proofing costs equal to or less than the present-day value of damage would normally be economically justified.

FLOOD PROOFING COSTS

The cost of flood proofing a building will depend on a variety of factors including the building's condition, the flood proofing technique to be employed, and other site-specific issues such as soil conditions and flooding levels. Information from experienced flood proofing construction costs adjusted for location and updated to January 1993 are provided to assist in economic analysis and to provide building owners estimates of costs for reconnaissance type planning of flood proofing measures. Data from *Means Construction Costs* publications were used to adjust and supplement actual construction costs obtained from FEMA, COE, and other sources. The *Means* publications contain adjustment tables for comparing average construction costs for the United States with costs for individual cities. There is also a table for updating historical costs to present-day cost values. These tables are included in the annual editions of cost data published by *Means*. The *Engineering News-Record* and other publications contain similar cost data. Add 10 percent to estimated costs to account for contractors profit. Professional engineering design of selected flood proofing measures should also be factored into the total cost.

Elevation

Wood Frame Building on Piles, Posts or Piers[1] ..... $26 per square foot
Wood Frame Building on Foundation Walls[1] ..... $19 per square foot
Brick Building[1] ..... $32 per square foot

[1] *These costs include foundation, extending utilities, and miscellaneous items, such as sidewalks and driveways. They do not include the cost of fill or landscaping.*

Slab-on-Grade Building[1,2] ..... $30 per square foot

[2] *The unit cost is based on a 2-foot raise. Add $1 per square foot for each additional foot raise up to eight feet.*

Fill (includes hauling and compaction) ..... $10 per cubic yard
Landscaping (no trees, bushes, or flowers) ..... $ 5 per square yard

Relocation

Moving Building (complex buildings being moved several miles) ..... $10 per square foot
Moving Building ..... $ 5 per square foot
(simple wood frame building being moved a few hundred feet)

Additional costs for this measure will include: the appropriate elevation cost listed above and may also include: fill, lot, landscaping, and pertinent indirect costs.

Floodwalls and Levees

Floodwalls, two feet above ground level ..... $ 77 per linear foot
Floodwalls, four feet above ground level ..... $113 per linear foot
Floodwalls, six feet above ground level ..... $160 per linear foot

Levees, two feet above ground level	$ 34 per linear foot
Levees, four feet above ground level	$ 63 per linear foot
Levees, six feet above ground level	$105 per linear foot

Levee costs include landscaping. Additional costs that may need to be estimated for both floodwalls and levees are as follows:

Interior Drainage	$3,800 lump sum
Closures	$ 66 per square foot
Riprap	$ 28 per cubic foot
Sidewalk	$ 9 per linear foot
Driveway (Asphalt)	$ 6 per square yard
Driveway (Concrete)	$ 16 per square yard

Dry Flood Proofing

Sprayed-on cement (1/8 inch)	$ 3 per square foot
Asphalt (2 coats below grade)	$ 1 per square foot
Periphery drainage	$ 28 per linear foot
Plumbing check valve (6")	$600 lump sum
Pump (submersible sump)	$500 lump sum
Flood shields	
Metal	$ 66 per square foot
Wood	$ 21 per square foot

For purposes of this analysis, the costs for various flood proofing methods listed above can be used as an initial planning estimate. For the example home, the unit cost of $33 per square foot for raising an existing slab-on-grade structure is appropriate. The example home measured 30 feet by 42 feet for a total floor space of 1,260 square feet. Thus, the estimated cost to elevate the example home was $41,580. To place fill under the elevated home, the unit cost of $10 per cubic yard was used. The amount of fill, based on a 1 vertical to 3 horizontal side slopes and elevating the building 5 feet, was 969 cubic yards for an estimated fill cost of $9,690. See Figure A-16 on page A-21. Landscaping was estimated at $5 per square yard for 344 square yards with a cost of $1,720. Costs for additional living expense during time away from the home were based on five days and three persons ($670). Loss of income was estimated for three days at $200 per day ($600). This loss involved the time away from the homeowner's job to deal with the engineering and construction contracts for the flood proofing measure. A location adjustment factor of 1.13, obtained from Means Constructions Costs publications, gave a subtotal cost of $61,314. A profit of 10% also needed to be included, as well as engineering costs of $7,000. Thus, the total cost of this flood proofing project was estimated to be $74,445. Maintenance costs were viewed as minimal and not included. When compared to the present value ($108,700) of the estimated damage prevented over the life of the structure, this estimated cost of flood proofing would be economically justified. This information and other factors discussed in the main text motivated the homeowner to a more in-depth assessment of flood proofing.

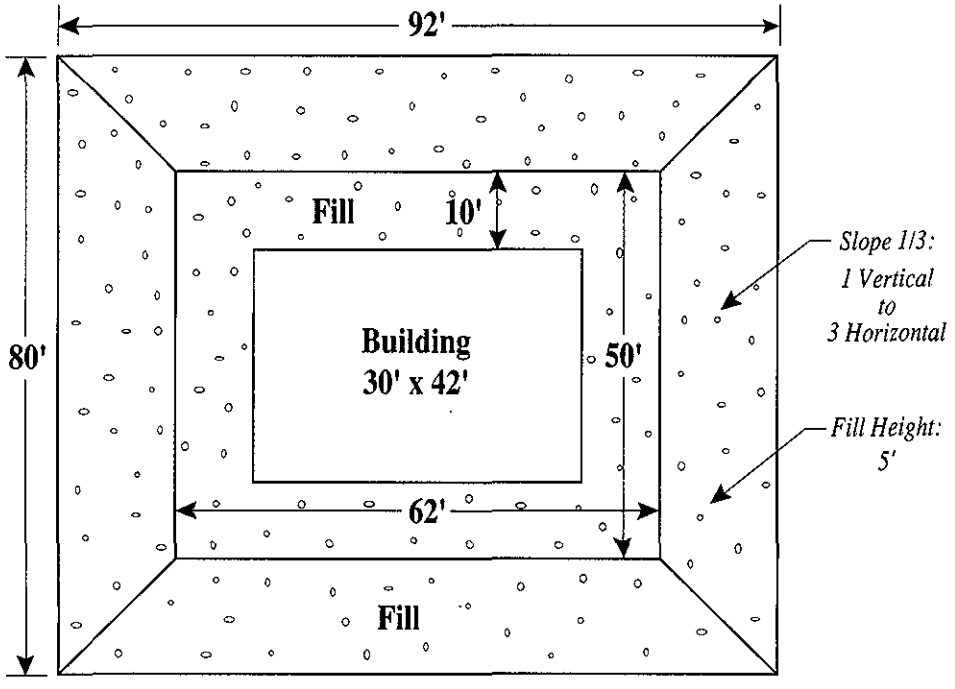
DETAILED ESTIMATES OF FLOOD PROOFING COSTS

At this stage, property owners should obtain at least three cost estimates for flood proofing from different contractors. Owners should keep in mind that the contractor submitting the lowest bid may not be best qualified to do the work. Any contractor bid represents cost estimates only; special situations may arise during the course of work that may alter actual costs incurred. Conditions for additional costs should be covered in the signed construction contract. In addition to the initial costs,

there may be future maintenance costs depending on the flood proofing method employed.
In this example, the property owner obtained three cost estimates for elevating his home—$64,500, $66,000, and $80,000. These bids included engineering design of the flood proofing work. The owner eliminated the third contractor because the bid was significantly higher than the estimated cost. The first two contractors, however, gave estimates well below the present worth of the benefits calculated and very close to the estimated cost. He questioned both low-bid contractors concerning the $1,500 difference in their estimates and found that the second contractor would assure completion of the project prior to the flood season. He also found that the second contractor's past clients were more satisfied with the work performed for them. After viewing projects completed by both contractors, he thought that homes elevated by the second contractor appeared superior to those done by the first contractor. Therefore, he selected the second contractor because he believed the extra investment would be worth the added quality of work he anticipated and the extra flood protection.

Included in Appendix B are a work sheet and graphs to use when performing a detailed economic analysis for flood proofing.

FIGURE A-16 — COMPUTATION OF FILL



Width (Top of Fill) = Building Width + 20'
Length (Top of Fill) = Building Length + 20'
Width (Bottom of Fill) = Top Width (50') + 2 [Horizontal Component of Slope (5' x 3')]
Length (Bottom of Fill) = Top Length (62') + 2 [Horizontal Component of Slope (5' x 3')]
Area (Top of Fill) = Width (50') x Length (62') = 3,100 sq. ft.
Area (Bottom of Fill) = Width (80') x Length (92') = 7,360 sq. ft.
Volume of Fill = Height x $\left(\frac{\text{Area of Top + Area of Bottom}}{2}\right) \div 27$ = 969 cu. yd.

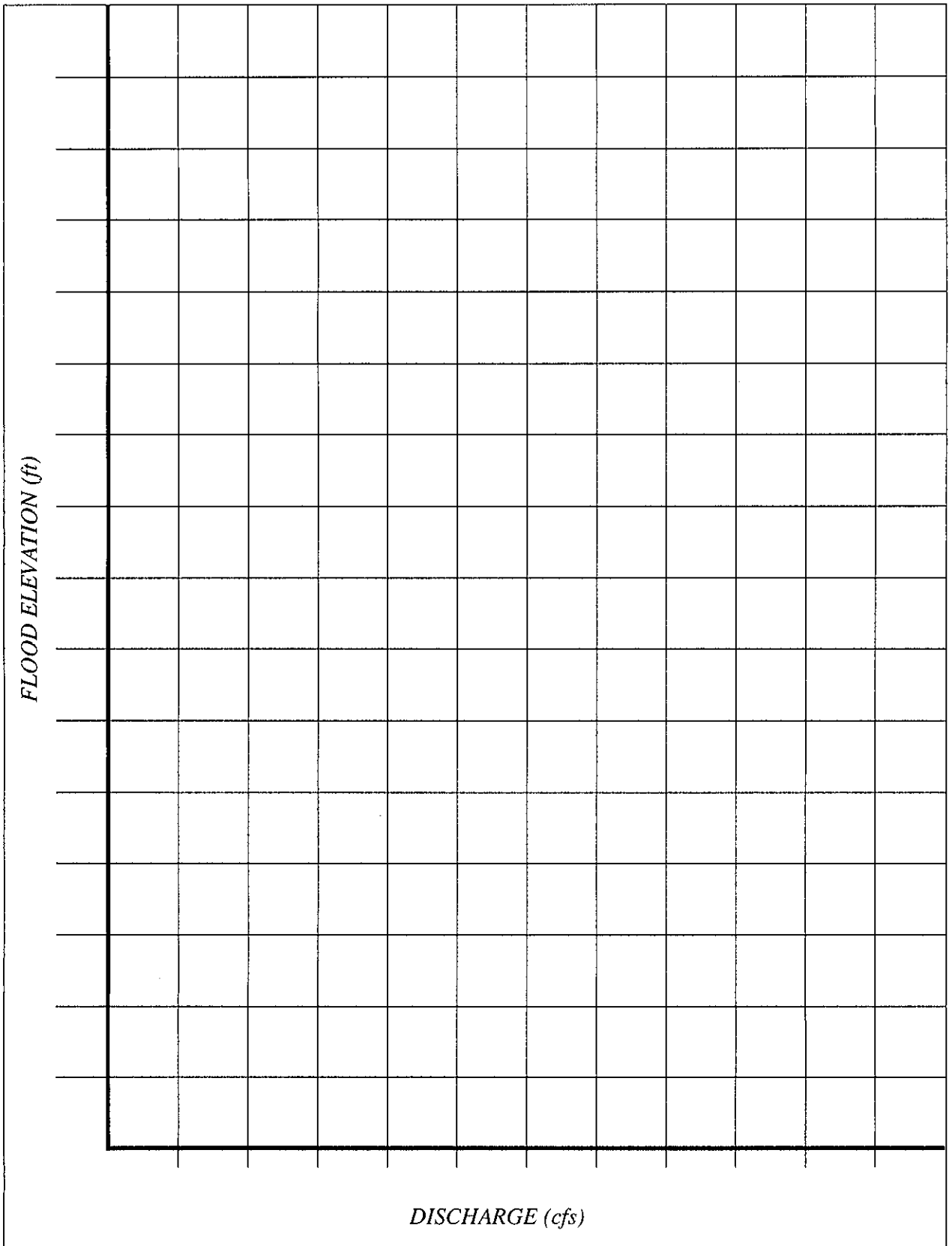
APPENDIX B

WORKSHEET AND GRAPHS

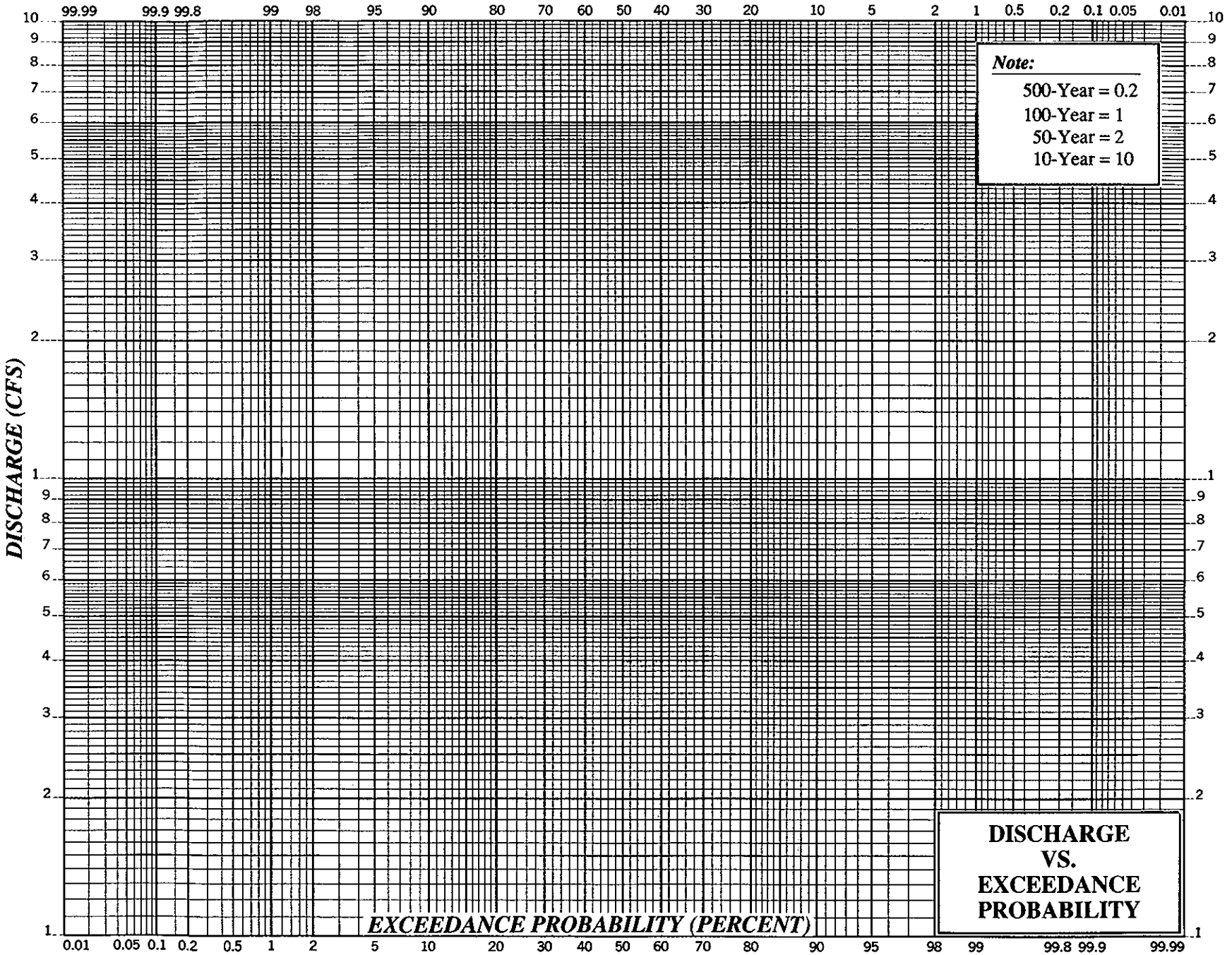
FOR PERFORMING A DETAILED ECONOMIC ANALYSIS

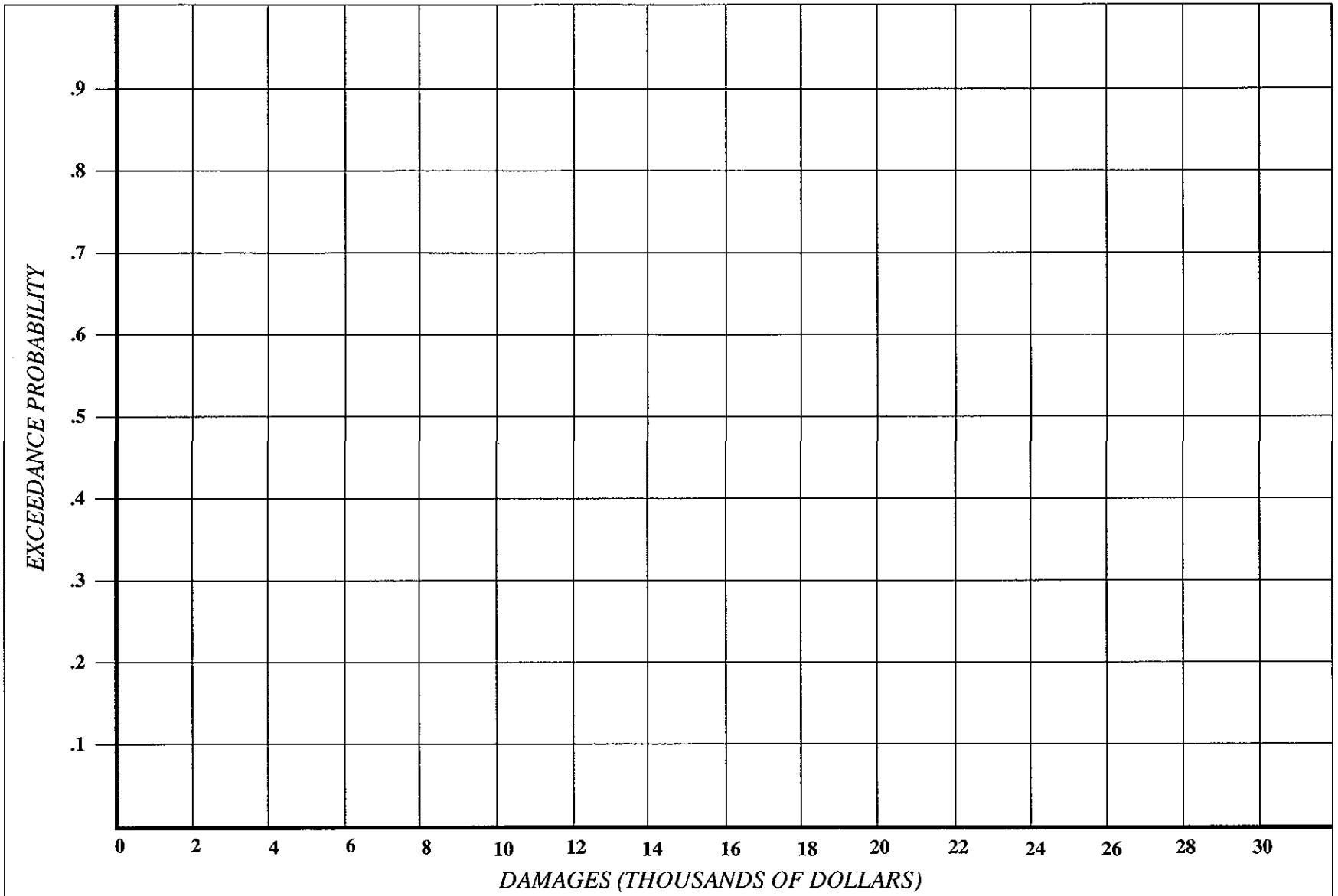
WORKSHEET

FLOOD PROOFING—HOW TO EVALUATE YOUR OPTIONS



Discharge Versus Elevation (Rating Curve) *Date* _____


DISCHARGE (CFS)
EXCEEDANCE PROBABILITY (PERCENT)
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
Note:
500-Year = 0.2
100-Year = 1
50-Year = 2
10-Year = 10
DISCHARGE VS. EXCEEDANCE PROBABILITY



Probability Versus Damage *Date* _____

APPENDIX C

CASE STUDIES – EVALUATING FLOOD PROOFING OPTIONS

APPENDIX C

CASE STUDIES—EVALUATING FLOOD PROOFING OPTIONS

Property owners who flood proof do so for a variety of reasons. Some will flood proof their buildings only if it is economically feasible. Others will do it to eliminate inconvenience and frustration. Still others will do it for simple peace of mind. Whatever the reasons, property owners must assess their financial and personal situations as well as analyze the flood risks to determine what flood proofing options are best. This assessment should include the availability of technical and financial assistance from governmental or other sources. From this assessment, property owners will be able to make a decision in their best interest.

The following cases illustrate a few of the many reasons property owners choose or reject flood proofing. Some approximate approaches to estimating economic viability of flood proofing are illustrated in the case studies. The last case illustrates the value of flood proofing for a commercial structure.

CASE A

The first case involves an accountant who has lived in a northeastern state for 12 years. His one-story home is constructed slab-on-grade with no basement. Over the past eight years, his home has been flooded six times by a stream (Flat Rock Brook) running directly behind his property. Flood depths in his home have ranged from a few inches to approximately four feet in a 1989 flood. After restoring his home for the sixth time in eight years, he contacted the COE about steps he could take to reduce future flood damages. The COE sent him several reports and brochures on flood proofing methods and programs. The possibilities of flood proofing intrigued him, so he investigated further to determine viable options.

He began by assessing his flooding situation, as discussed in Chapter Four, utilizing the FIS published by FEMA as well as his own and his neighbors' flooding experiences to evaluate his flood proofing options. Since the stream could rise quickly without warning, he ruled out sealants and barriers requiring closures because sufficient warning time would not be available to install the closures. Since his house is located on a non-permeable soil, he knew that constructing an earthen barrier or elevating the house on fill might be feasible options. However, he determined the potential flood depth for flood proofing to be five feet and decided that an earthen barrier may be impractical due to the amount of land required to achieve the proper side slopes. He also felt that the cost of a floodwall designed for five-foot hydrostatic force would be prohibitive. Since his home is not subject to ice and debris flow, he concluded that elevating the house would not require special structural measures to withstand impact forces from such flows. Thus, he decided to elevate or relocate his house. He was willing to accept occasional damage to his lawn and yard, as long as the house itself would be protected from large, infrequent floods. Rather than moving his house to another property—an expensive undertaking— he decided to elevate it so that the first floor would be at the 100-year flood level. (Note: Other protection levels, either higher or lower could be selected in different circumstances.)

As an accountant, he was naturally curious about how much money he could spend today to flood proof his home and get an equivalent return on his investment by not having to clean up and repair his home after flooding. Using flood hazard information available in his community's FIS, he performed a detailed economic analysis and found that, by elevating his home to the 100-year flood elevation, he could save an average flood damage amount of $11,535 per year. He converted this annual damage into a present worth value (using 30 years as the life of his home and 10% interest rate) and found that he could invest up to $108,700 now to flood proof his home to the 100-year flood level, an amount that would be

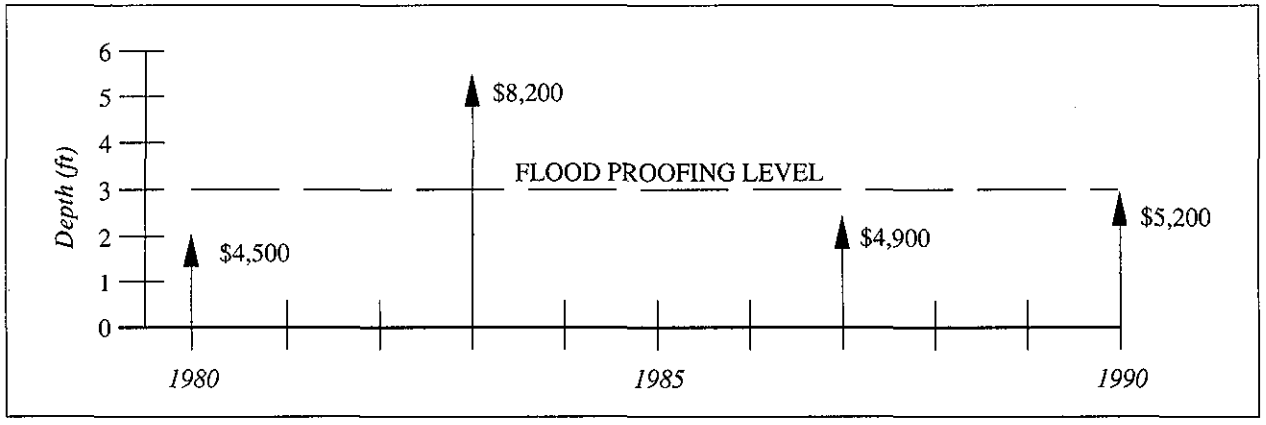
economically justified. Appendix A explains how he performed his detailed economic analysis, including contractual arrangements for construction. Although economics are the primary consideration in this example, other factors, such as inconvenience and secondary benefits, motivated the accountant to accept the costs of flood proofing.

CASE B

This case involves a simple economic approach by a retired couple whose home in a midwestern state had been flooded by the river behind their house four times in ten years. In 1980, floodwaters two feet deep inundated their home causing $4,500 in damages. In 1983, floodwater depths reached 5.5 feet, causing $8,200 in damages. In 1987, they spent $4,900 to repair damage caused by 2.5 feet of flooding. Finally, in 1990, their home was again flooded, causing damages of $5,200 from three feet of floodwaters. Because their community was not participating in the NFIP, they had been unable to obtain flood insurance, and thus had to carry the total financial burden of repairing their house.

The timeline below shows the flooding depths and associated repair costs for the time the couple lived in their home. The flooding events in 1980, 1987, and 1990 ranged from two to three feet deep but the 1983 flood rose to 5.5 feet. The homeowners decided that flood proofing to the 5.5 foot level would be too expensive. Rather, they would risk the less frequent large flood and flood proof to the three-foot level, which would have prevented damages from three of the four floods they suffered.

HISTORICAL FLOOD DAMAGE FOR CASE B



To determine how much they could afford to invest in flood proofing, the couple totaled their repair expenditures following the floods of three feet deep or less. This total was $14,600 over the ten-year period. By flood proofing to the three-foot level, they could have prevented $1,460 in damages per year. However, they learned that a neighbor had not experienced flooding during the the ten years preceding the 1980 flood. Therefore, the couple assumed their home had not been damaged by floods for the ten years before they moved in. They then spread the total damage cost of $14,600 over 20 years, yielding an average damage cost prevented by flood proofing of $730 per year. Using the present worth formula, they estimated the amount of money they could invest in flood proofing and be paid back by flood damages prevented over the life of their mortgage.

Assuming a loan interest rate of 9% for a 20-year period—the amount of time left on their mortgage—they found they could spend about $6,700 on flood proofing to the three-foot level, an amount they considered to be economically justified. They found a qualified contractor who sealed their home to the

three-foot level. The total cost of flood proofing their home was $4,500, which left approximately $2,200 for any future operation and maintenance costs such as repairing sprayed cement. The dry flood proofing measure involved 1/4-inch application of sprayed cement on cinder block construction. Flood shields were provided for doors and windows that could be removed and stored in a convenient location during non-flood periods.

Case C

Consider next the case of a banking executive who has lived in her home in a small eastern city for 13 years. Her two-story, brick home without a basement was flooded, often twice yearly, by the river behind her house. These floods normally occurred during the spring, due to rain and snowmelt runoff. Floodwaters would usually rise from one to three feet into her home, not receding for several days. She and her family would have to stay at her mother's house nearby until the floodwaters lowered and the house could be cleaned and utilities restored—a process that often took three weeks or longer.

Over the years, she became an expert at restoring her flood-damaged home. The routine was always the same: take time off from work to drain standing water, repair sagging floors, gather debris, and wash the house with a hose; hire and wait for electricans, plumbers, and other service professionals to restore utilities; and clean or, in some cases, buy new furniture, carpeting, and clothes. Eventually, during every hard rain, she and her family would nervously anticipate a flood. Although she had flood insurance to cover some of the financial losses, she and her family tired of the inconvenience of frequent flooding. She decided to flood proof, provided the costs were reasonable and the flood proofing measure aesthetically pleasing.

Since her home was normally flooded by shallow water depths that were slow-rising, slow-moving, and free from ice or debris, she concluded that sealing the walls and providing appropriate closures to the three-foot flood elevation was her best flood proofing option. A qualified contractor performed the work to her satisfaction for a reasonable price, providing peace-of-mind and reducing the likelihood of damage from periodic flood events.

Case D

This case involves a successful entrepreneur who built her dream home in a Los Angeles suburb. Located at the base of a mountain overlooking the city, her home was serene and peaceful, yet close to her business and the conveniences of the city. However, the house was built in an area subject to alluvial fan flooding. In 1990, her home was severely damaged by a flood event that exhibited characteristics of this type of flooding, which can occur in arid and semi-arid climates. Flow paths on an alluvial fan can be unpredictable, often migrating during the course of a flood. Alluvial fan flooding normally brings high velocity flows (15-30 feet per second) with little warning, exerting large hydrodynamic forces on buildings. It may also cause severe erosion and scouring from heavy sediment and debris transport and deposit, with debris flow as much as several feet deep.

The flooding that hit the woman's home carried rocks and trees that severely damaged the walls of the house. Family members were in the house at the time of the flood and were nearly killed. Portions of the house were covered with sediment deposits up to two feet deep. When the owner had her home rebuilt, she investigated ways to protect her house from future damage. She found she had only two flood proofing options: move the house away from the alluvial fan or build large structural components to safeguard the house from future flood damage. She and her family could not bear the thought of moving their dream home from such a desirable location. Therefore, the house was converted into a huge, almost

fortress-like concrete structure that could withstand the heavy forces from high-velocity flow and debris transport by a professional engineering and construction firm. Design and construction costs were almost 40 percent of the house's value but to the owner it was worth it to stay on the property and live in a structurally sound home. Knowing from experience that flash floods could occur, the owner sought assistance from professional flood warning experts. The experts provided a flood warning plan that included conditions when the home would be unoccupied. This plan involved family members spending nights away from their home when flood warnings or rainfall greater than 1.0 inch were forecast by the weather service. Daytime evacuation was to be based on observed runoff conditions and flood forecasts. Although this plan required some inconvenience, the owner realized that it was necessary to avoid hazards to the family and their friends.

Case E

This is the case of a retired couple who reside in a beachfront home in a south Atlantic coastal community. Their house was located well above sea level, but below the 100-year flood elevation shown on their community's FIRM. They realized that a hurricane might destroy their house by the awesome power of waves.

The owners had no flood insurance because they purchased the house prior to the establishment of the NFIP in 1968 and were therefore not required to carry flood insurance. They considered leaving the home at its present elevation and purchasing voluntary flood insurance to cover any financial losses. However, the prospect of losing their home and belongings to a hurricane was quite unsettling. They wanted to continue to live comfortably and safely in their home in its prime beach location. An engineering firm elevated their home on piers above the 100-year flood elevation plus wave allowance, in accordance with FEMA's coastal construction code, and provided aesthetic enhancements to maintain the appearance of the home. The total cost of the project was approximately 25 percent of their home's value. In addition, the owners could now purchase flood insurance at a much cheaper rate since their home was elevated above the 100-year flood elevation as shown on their community's FIS.

Case F

Combining flood proofing barriers with wet flood proofing measures, developers of a commercial/residential project in an eastern metropolitan city turned an unsightly, deteriorating industrial area in a floodplain into one of the nation's most valuable pieces of real estate. Constructed on the banks of a large river, the 3.5-acre complex consists of two upscale office and condominium buildings that share a common foundation and parking garage. An innovative, almost invisible flood proofing system with retractable floodgates protects the complex and its shops, restaurants, and businesses.

Specifically designed to preserve the scenic views and water access during non-flood conditions, the floodwall system includes 58 watertight floodgates hidden in vertical pockets in the parking garage beneath the plaza. A counter-flooding system protects the complex from hydrostatic uplift.

The slow-rising floodwaters of the river were an important consideration in the design of this system. A minimum 12-hour warning is required to raise the floodgates and form a continuous floodwall protecting the complex. The gates are located in place between concrete pylons disguised as ornamental columns topped with globe lights.

Floodgates are equipped with inflatable seals—designed to withstand the pressures of a 100-year flood—

running continously around three edges of the gate. When inflated, the seals provide a watertight barrier when the gate is raised. The force of the water on a P-seal on the back side of the gate provides an absolutely dry condition on the land side. Once the gates are raised, the seals are inflated with a hand-held air compressor.

For aesthetic reasons, the 58 gates are hidden in vertical pockets beneath the plaza until flooding occurs. A crane then lifts the gates from their pockets. Together, the 58 flood gates and five swing gates (located at service entrances) provide 960 linear feet of floodwall protection. In the plaza area, the gates run continously for 590 linear feet. Building walls serve as a flood barrier where possible.

At six feet above flood stage, the complex becomes an island. Without protective measures, hydrostatic uplift could cause portions of the building and plaza to pop up like a cork. To prevent this, a carefully controlled counter-flooding system floods the lower level of the parking garage. Designed for redundancy, the counter-flooding system consists of three inlet screens, three intake structures, and five pipes. For aesthetic reasons, the intake structures—each 17 feet long—are concealed below benches outside the floodgates. To prevent excess debris from entering the garage, these structures collect water from below the debris-filled surface of the floodwater. Through a series of valves located on the upper level of the parking garage, the water is gradually introduced into the lower level. To control ballasting, the system introduces one inch of water into the garage for each inch the river rises. Each pipe is equipped with two valves to ensure that the water can be shut off manually or with electric motors. After a 100-year flood, two 800-gallon-per-minute sump pumps can evacuate eight million gallons of water from the parking garage in only 3.5 days.