Chapter 5.
Direct Physical Damage - General Building Stock

5.1 Introduction

This chapter describes methods for determining building damage to the general building stock associated with riverine and coastal flooding, as well as methods for estimating damage related to floodwater velocity. The flowchart of the overall methodology, highlighting the building damage component and showing its relationship to other components, is shown in Figure 5.1.

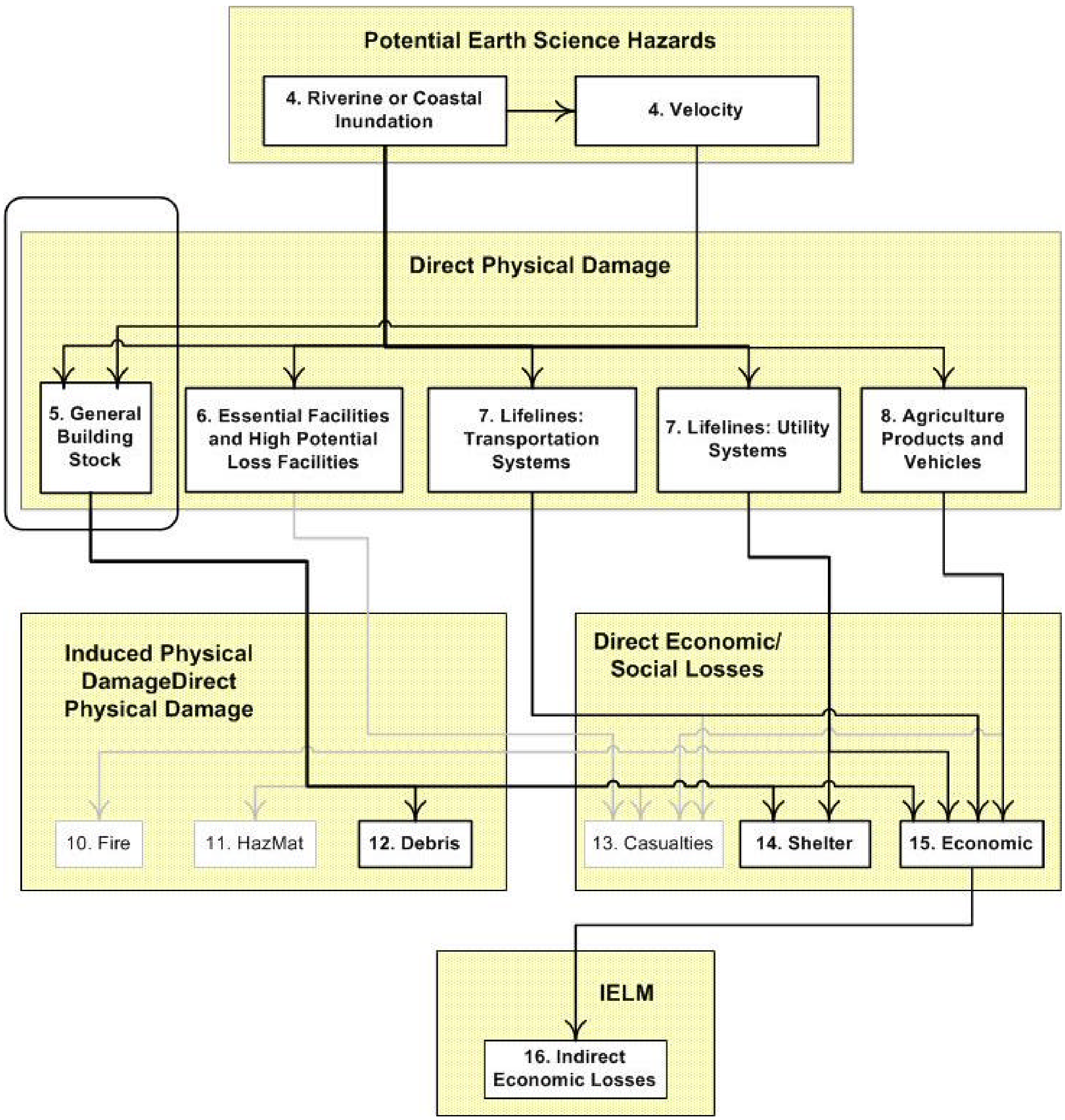

Figure 5.1 Building Damage Relationship to Other Components of the Methodology

5.1.1 Scope

This chapter focuses on the loss estimation process as defined by HAZUS®*MH* for the flood model. The scope of this chapter includes development of methods for estimation of flood damage to buildings and contents given knowledge of the occupancy and its typical configuration (e.g., foundation type and assumed first floor elevation), and an estimate of the depth of flooding throughout the study area. The extent of damage to the building and its contents is estimated directly from the depth of flooding by the application of a depth-damage curve associated with each occupancy class. Building parameters related most directly to flood damage are discussed in Section 5.2

Section 5.3 discusses the various sources of residential and non-residential depth-damage curves from which the HAZUS®*MH* damage function library was developed. This section also identifies the default damage curve associated with each occupancy class. Section 5.4 provides flood damage models for velocity, Section 5.5 describes models for damage reduction resulting from warning, and Section 5.6 addresses the flood models treatment of uncertainty. Finally, Section 5.7 provides guidance for expert users, including a discussion of estimation of benefits associated with flooding and natural floodplains.

5.1.2 Input Requirements and Output Information

Input required to estimate building damage using depth damage curves includes the following two items:

- Occupancy class, foundation type, and assumed first floor elevation, typically related to the development era (e.g., pre-FIRM or post-FIRM)
- Depth of flooding throughout the census block

The "output" from a depth-damage curve is an estimate of the damage to the building(s) at a given depth, expressed as a percentage of the replacement cost of the structure(s), and later translated into dollars using the Valuation module (described in Chapter 14).

For the analysis of the general building stock in a given census block, the Flood Model assumes that the inventory is evenly distributed throughout the census block, and area-weighted estimates of damage (rather than depth) are utilized to reflect the variation in flood depth throughout the block. (Area weighted depths are not used, as many of the depth-damage curves are non-linear). While the depth damage curves may be applied to a single building as well as to all buildings of given type, they are more reliable as predictors of damage for large, rather than small, population groups. The user is advised to use and report the results with the appropriate amount of caution.

5.1.3 Form of Damage Functions

As noted, flood damage functions are in the form of depth-damage curves, relating depth of flooding (in feet), as measured from the top of the first finished floor, to damage expressed as a percent of replacement cost.

Depth-damage functions are provided separately for buildings and for contents. For flood loss analyses, buildings are defined to include both the structural (load-bearing) system, as well as architectural, mechanical and electrical components, and building finishes. (This varies from the earthquake loss analysis definition wherein the structural components are limited to the load-bearing system, and the non-load-bearing systems, such as architectural, mechanical, electrical, and finishes are defined as "non-structural".)

5.2 Building Parameters Related to Flood Damage

Unlike the earthquake model where the model building type, design level and quality of construction all play a critical role in the structure's ability to resist earthquake damage, these features do not play a major role in damage resistance to flooding. Unless the floodwaters flow at a high velocity and the structure and the foundation become separated, or the structure is impacted by flood-borne debris, it is unlikely that a building will suffer structural failure in a flood. (Structural failure should be distinguished, however, from suffering substantial damage, wherein the damage due to inundation exceeds 50% of the structure's total replacement cost and the building is considered a total loss.) In general, it is expected that the major structural components of a building will survive a flood, but that the structural finishes and contents/inventory may be severely damaged due to inundation.

5.2.1 Building Age

Building age is a key parameter for estimating expected flood damage. Age is an issue because building codes (and expected building performance) change over time, and because development regulations change when a community enters the National Flood Insurance Program (NFIP). For example, if half of the total building floor area of a census block was developed prior to entrance in the NFIP, then it can be assumed that this half of the exposure will be more susceptible to damage resulting from a 100-year flood event.

To address the issue of age, both sources of the HAZUS Flood Model's inventory data (U.S. Census and D&B, see Chapter 3) were reviewed for content of this data. The Census data does provide a range of year of construction at the Block Group level. The ranges are in decades starting with pre-1939 structures and including every decade up to 1990, as seen in Table 3.8. It can be assumed that typical development practices will result in the homogenous development of all blocks within a single block group. In other words, the commercial/industrial development and the residential development throughout the block group are assumed to occur concurrently. It is therefore possible to distribute the census block group age distribution throughout the constituent census blocks, as well as to assume that this distribution is applicable to non-residential development.

5.2.2 Foundation Type and First Floor Elevation

Because first floor elevation (as determined from foundation type) is another key parameter for the estimation of flood damage, information on foundation types for the general building stock is required. Within the HAZUS Flood Model, all census blocks have been assigned a code identifying the primary local flood hazard type as well as a foundation mapping scheme. The rules for the census block mapping schemes are as follows:

- The default value for all census blocks is “R” (riverine).
- Those census blocks that are immediately adjacent to the Great Lakes have been coded as “L” for Great Lakes.
- Those census blocks that are within the FEMA Q3’s for coastal regions will be coded as “C” (coastal).
- For those blocks with both riverine and coastal hazards, it is assumed that the coastal foundation practices will dominate, since the building codes for coastal are more stringent.

5.2.3 Model Building Types

Although most flood depth-damage functions are independent of structural system or construction material, the HAZUS®*MH* inventory database includes Model Building Type as a basic parameter because of the importance of structure type to the estimation of earthquake and hurricane damage. Within the Flood Model, the Model Building Types are a simplified version of the ones used by the HAZUS Earthquake Model, and are listed in Table 5.1.

Table 5.1 Model Building Types

No.	Label	Description	Height			
			Range		Typical	
			Name	Stories	Stories	Feet
1	Wood	Wood (light frame and commercial and industrial)		All	1 to 2	14 to 24
2	Steel	Steel frame structures including those with infill walls or concrete shear walls	Low-rise Mid-rise High-rise	1-3 4-7 8+	2 5 13	24 60 156
3	Concrete	Concrete frame or shear wall structures including tilt-up, precast, and infill walls	Low-rise Mid-rise High-rise	1-3 4-7 8+	2 5 12	20 50 120
4	Masonry	All structures with masonry bearing walls	Low-rise Mid-rise High-rise	1-3 4-7 8+	2 5 12	20 50 120
5	MH	Mobile Homes		All	1	10

A general discussion of the five (5) structural systems is provided in the following sections.

Wood (W)

Within the HAZUS model, there are two general types of wood structures: 1) small, multi-family or single family dwellings of not more than 5,000 square feet of floor area; and 2) large multi-family, commercial, or industrial buildings of more than 5,000 square feet of floor area. The essential structural feature of the smaller (5,000 square feet or less) buildings is repetitive framing by wood rafters or joists on wood stud walls. These buildings may have masonry chimneys and may be partially or fully covered with masonry veneer. Most of these buildings, especially the single-family residences, are not engineered but are constructed in accordance with "conventional construction" provisions of building codes. The floors and roofs may be sheathed with sawn lumber, plywood or fiberboard sheathing. Walls are covered with boards, stucco, plaster, plywood, gypsum board, particleboard, or fiberboard, or a combination of several materials. Interior partition walls are usually covered with plaster or gypsum board.

The larger buildings (floor areas greater than 5,000 square feet) have framing systems consisting of beams or major horizontal members spanning between columns supporting lighter floor joists or rafters. These horizontal members may be glue-laminated wood, solid-sawn wood beams, wood or steel trusses, or steel beams. The exterior walls are covered with plywood, stucco, plaster, other types of paneling, or a combination of materials. The interior surfaces of the walls and interior partitions usually are covered with gypsum board or plaster.

Steel (S)

Steel buildings are usually framed with a series of steel girders spanning between steel columns supporting beams and various forms of wood or concrete floors and roof. Exterior walls are constructed of steel siding, window walls, or cladding panels, but may include cast-in-place concrete shear walls or unreinforced masonry infill walls. If ceilings are used in these buildings they are usually suspended acoustical tiles. These buildings most commonly house offices, warehouses, commercial, or industrial occupancies. Floor areas for these buildings cover a broad range with an approximate minimum of 3,000 square feet.

Concrete (C)

Concrete buildings are those where the structural frames and/or exterior walls are made of reinforced concrete, either cast-in-place, pre-cast tilt-up, or pre-cast elements. Interior framing can be steel, wood, concrete, pre-cast, or any combination. These buildings are most commonly used for office, warehouse, commercial, or industrial occupancies. Interior finishes are usually concrete, gypsum board, or plaster.

Masonry (M)

Masonry buildings are those where the exterior walls are masonry, either reinforced or unreinforced. These buildings are most commonly used for office, warehouse, commercial, industrial, or multi-family occupancies. Interior finishes are usually, concrete, gypsum board, or plaster.

Mobile Homes (MH)

These are prefabricated housing units that are trucked to the site and then placed on isolated piers, jack stands, or masonry block foundations (usually without any positive anchorage). Floors and roofs of mobile homes usually are constructed with plywood and outside surfaces are covered with sheet metal.

5.3 Building and Contents Damage Due to Flooding

The HAZUS$^{®MH}$ Flood Model methodology for estimating direct physical damage (e.g., repair costs) to the general building stock is fairly simple and straightforward. For a given census block, each occupancy class (and foundation type) has an appropriate damage function assigned to it (i.e., 1-story, no basement), and computed water depths are used to determine the associated percent damage. This percent damage is multiplied by the full (and depreciated) replacement value of the occupancy class in question to produce an estimate of total full (and depreciated) dollar loss. In addition to the library of damage functions (including FIA "credibility-weighted" damage functions, as well as various USACE District functions), inventory data on foundation type and first floor elevation, the presence of basements and estimates of the number of stories are required (see Chapter 3 for more discussion of inventory parameters).

5.3.1 Compilation of Depth-Damage Functions

Estimation of direct damage to the general building stock (percent damage to structures and their contents) is accomplished through the use of readily-available depth-damage curves, compiled from a variety of sources including the Federal Insurance and Mitigation Administration (FIMA) FIA[1] "credibility weighted" depth-damage curves, and selected curves developed by the U.S. Army Corps of Engineers (USACE), and the USACE Institute for Water Resources (USACE IWR). Functions have been compiled for the USACE Chicago, Galveston, New Orleans, New York, Philadelphia, St. Paul, and Wilmington Districts. While default damage functions have been selected for each occupancy class, all referenced damage functions have been incorporated into the damage function library housed within the software and are available for user review and selection.

5.3.1.1 FIMA (FIA) Residential Depth-Damage Curves - Riverine

FIMA (formerly known as the FIA) is responsible for administering the National Flood Insurance Program (NFIP). FIA has created national depth-damage curves that are used in the actuarial rate setting process. The original depth-damage functions, developed in 1970 and 1973,

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[1] During recent re-organizations at the FEMA, the Federal Insurance Administration (FIA) and the Mitigation Directorate were combined into a single entity called the Federal Insurance and Mitigation Administration (FIMA). However, because the damage functions were published as the FIA credibility-weighted functions, they will continue to be referred as FIA depth damage functions.

are referred to as "theoretical base tables." Some of the information used to develop the initial curves came from post-flood surveys conducted by the Corps of Engineers.

With time, a wealth of damage and loss data has been collected as part of the flood insurance claims process. Losses include both structure and contents losses, and are determined relative to actual cash value (depreciated replacement cost). The majority of claims are for residential structures. The FIA damage functions are updated annually based on this damage data, as part of the flood insurance rate review process. A statistical "credibility" analysis is used to combine the "theoretical base tables" with the "rate review" results. When sufficient claims exist to provide statistical confidence in the results, the depth-damage relationship is based exclusively on the claims data. When claims data are insufficient, the claims data and base tables are combined using a weighting process. The result is two sets of curves: pure summaries of claims data, and credibility analyses combining available claims data into weighted curves.

The "Depth Damage" report prepared by the NFIP Actuarial Information System (1998)[2] indicates that actual depth-damage claims data are available for 10 categories of structures. Each category, along with the historic number of claims for the period of 1978 – 1998 are given below.

1. One floor, no basement (255,717 claims)
2. One floor, with basement (3,310 claims)
3. Two floors, no basement (65,623 claims)
4. Two floors, with basement (86,236 claims)
5. Three of more floors, no basement (28,434 claims)
6. Three of more floors, with basement (28,989 claims)
7. Split-level, no basement (4,278 claims)
8. Split-level, with basement (10,280 claims)
9. Mobile home, no basement (8,182 claims)
10. Mobile home, with basement (285 claims)

According to the NFIP Actuarial Information System "Credibility and Weighting" report (1998), credibility analyses and the resulting weighted curves are available for six structure categories. These categories represent aggregations of the original ten categories:

1. One floor, no basement
2. Two or more floors, no basement
3. Two or more floors, with basement
4. Split-level, no basement
5. Split-level, with basement
6. Mobile home

[2] While the current discussion references FIA data through 1997, the final damage functions incorporated into the current version of the HAZUS Flood Model software are based on FIA data through 2001.

Categories with fewer documented claims will rely more heavily on the theoretical base tables. Figure 5.2 presents the six FIA credibility-weighted damage functions. It should be noted that several of the curves are not continuous. That is, because claims data are often sparse, damage values are not provided for all depths. For use in the HAZUS®MH software, missing damage values (e.g., damage at 6.0 feet for structures with two floors, no basement) have been interpolated between known water depths to facilitate damage function application.

5.3.1.1.1 Modification of FIA Single Family Residential Depth-Damage Curve to Reflect Basement Exclusions

As noted, the FIA claims data and "credibility-weighted" depth-damage curves reflect the limitations of FIA insurance coverage. That is, damage to items not covered by FIA policies (e.g., basement flooring and other finishes) will not be represented in the FIA damage functions. Because the intent of HAZUS®MH is to estimate total flood damages regardless of insurance

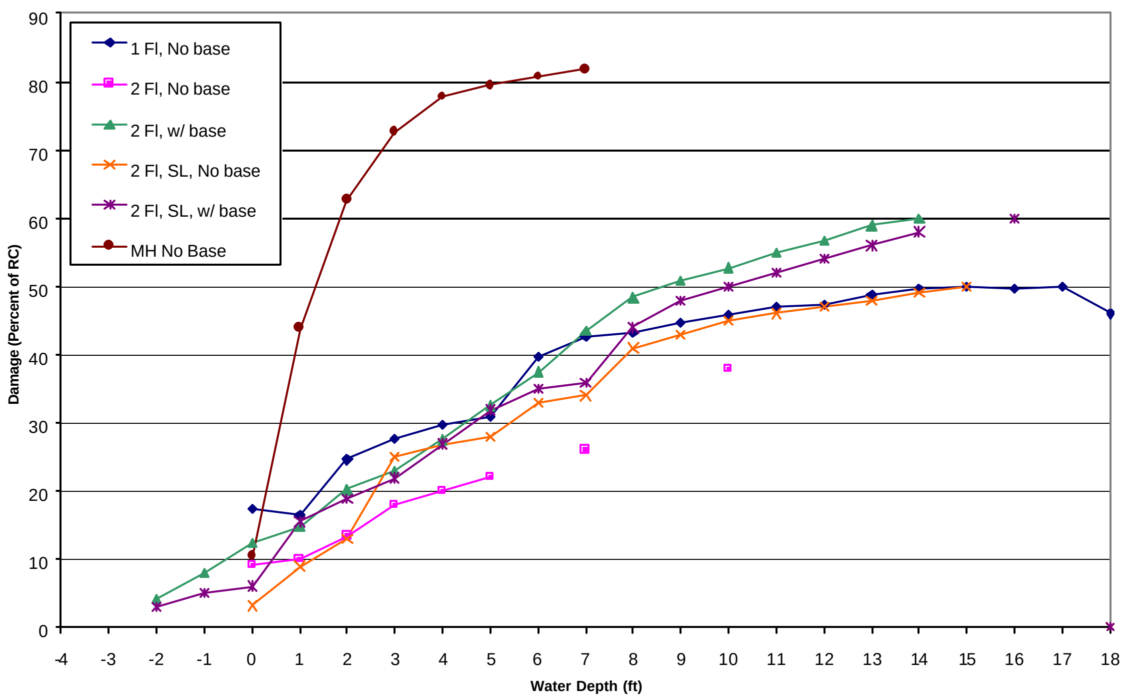

Figure 5.2 FIA Credibility-Weighted Building Depth-Damage Curves as of 12/31/1998

coverage, the damage functions for structures with basements (two-floor, with basement, and split-level with basement) were modified to estimate likely basement losses for use as a default damage function.

As outlined in the NFIP "Dwelling Policy," a number of coverage exclusions apply to basements, as well as to enclosures under elevated structures[3]. Basement exclusions include:

- Personal property (contents)

- Building equipment, machinery, fixtures and components, including finished walls, floors, ceilings and other improvements, except for required utility connections, fiberglass insulation, drywalls and sheetrock walls and ceilings but only to the extent of replacing drywalls and sheetrock walls in an unfinished manner (i.e., nailed to framing but not taped, painted or covered).

- Enclosure exclusions for elevated Post-FIRM buildings include:

- Personal property (contents)

- Building enclosures, equipment, machinery fixtures and components (except for required utility connections and the footings, foundation, posts, pilings, piers or other foundation walls and anchorage system as required for support of the buildings).

To estimate likely basement damage relative to FIA policy exclusions in basements, a distribution of basement component replacement cost, relative to the total structure replacement cost was required. Residential replacement cost models taken from "Means Square Foot Costs" (Means, 2000) were used to develop the component cost distribution given in Table 5.2. Table 5.2 also indicates the extent of the policy exclusion as it applies to each component. As shown, two-thirds of the cost of wall finishes are covered, while one-third is excluded (typically the cost to tape and finish, and paint the walls). Costs for floor finishes, finished ceilings, light fixtures and additional heating ductwork and also assumed to be excluded from coverage.

[3] It should be noted that the FIA V-Zone depth-damage functions reflect full coverage in any enclosures, and therefore do not require adjustment.

Table 5.2 Basement Component Cost Expressed as a Percent of Total Structure Replacement Cost– (two floors total, including the basement, assuming 1600 SF main structure)

	Econ.	Avg.	Custom	Luxury		
Total finished basement cost/SF of main	$14.25	$18.10	$26.10	$32.30		
Total Structure Cost/ SF, including basement	$69.00	$96.88	$125.63	$152.55		
Basement as a % of Total	21%	19%	21%	21%		
	Econ.	**Avg.**	**Custom**	**Luxury**	**Used for Final**	**Excluded**
Unfinished Basement Walls	9.7%	7.0%	7.4%	7.4%	8%	none
Wall Finishes	1.0%	1.3%	2.0%	2.0%	1.5%	~33%
Floor Finish	3.6%	3.5%	4.2%	5.5%	4%	100%
Ceiling	2.7%	3.3%	3.4%	3.0%	3%	suspended = 100%, drywall = ~33%
Heating	0.0%	0.6%	0.6%	0.6%	0.5%	100%
Lighting	3.6%	3.0%	3.2%	2.8%	3%	100%
Total	21%	19%	21%	21%	20%	

Likely flood damage thresholds for basement components were estimated by the project team for two basic conditions: 1) flood water at –4 feet (four feet below the top of the finished ground floor, approximately 4-5 feet of water in the basement, the lowest depth reported by FIA); and 2) flood water at -1 foot (basement assumed to be completely inundated). Damage to basement components have been estimated as follows:

- Unfinished concrete basement walls are not expected to suffer damages from flood waters of any height

- –4 feet (four feet below the finished ground floor, approximately 4 feet of water in the basement):

  - Floor finishes must be replaced (100% loss, 100% exclusion)

  - Due to water entry, seepage and moisture due to standing water, wall finishes will need to be replaced (100% loss, 1/3 exclusion)

  - Due to water entry, seepage and moisture due to standing water, ceiling tiles would need to be replaced, but the associated suspension system would be salvageable (damage = 33% of ceiling cost, 100% excluded). Drywall ceilings would require complete replacement (100% loss, 1/3 exclusion)

- Electrical plugs, receptacles and switches would need to be replaced (33% loss, 100% exclusion)
- Ductwork for heating would also require replacement (100% loss, 100% exclusion)

- -1 foot:
  - Ceiling suspension system requires replacement (remaining 67% of cost, 100% exclusion)
  - Light fixtures require replacement (remaining 67% of cost, 100% excluded).

To complete the damage curve modification, the excluded damage cost for each damaged component (expressed as a percent of total building replacement cost) was added to the tabulated FIA damage curve. A total of 7% damage was added in at –4 feet, with an additional 4% added in at –1 foot, for a total of 11% added damage. (This equates to the net basement value of 20% minus 8% for undamaged walls, and an additional 1% for items already covered by FIA, including 2/3 of the cost of wall finishes, and in some cases, part of ceiling costs.) The resulting structure damage curve for "two or more floors, with basement" is given in Figure 5.3. Figure 5.4 shows the curves for "split level, with basement."

The resulting curves may be compared to the limited claims data available for basement structures with water depths below 0 feet. While basement coverage was discontinued in 1983, it is assumed some of the claims data for basement buildings with damage below the first floor reflects claims made prior to the implementation of the exclusions. Review of the claims database for "two-floor with basement" structures (where 13 percent of the 86,236 claims were for structures with water depths less than 0 feet), indicates average damages (FPAVG – average damage amount divided by property value) on the order of 7-15 percent for water depths between –10 and -1 feet, roughly consistent with the proposed curve.

Similarly, contents claims data for a variety of basement structures ranged from about 15 - 40 percent for water depths between –10 and -1 feet. The "contents-residential, first floor only" CWDD curve reaches its maximum of about 60 percent damage at 10 feet of water, as does the "contents-residential, first floor and above" CWDD curve. The difference between these two curves is small, and both are based on a limited number of claims; approximately 57,000 claims contribute to the credibility weighting for the first curve, while only 17,400 claims are available for the second. The majority of claims are for depths of five feet and less, and full credibility (i.e., resulting curve based entirely on claims history) is available only for a depth of 1 foot for the first curve.

For comparison, detailed contents damage functions developed by the USACE New Orleans District (for structures with no basements) were reviewed. These expert opinion-based functions were developed on a component basis for one and 2-story structures. The resulting contents damage function for 1-story residence reaches its maximum damage of about 91 percent damage at 5 feet of water. At 5 feet, damage to the 2-story structure is 55 percent, and it reaches its maximum of 92.5 percent at 14 feet (approximately 5 feet above the finished second floor). This implies an approximate 60/40 split of contents on the first and second floor of a 2-story structure.

This information was used to adjust the FIA "credibility-weighted" depth damage functions for contents. Based on the limited claims data, it is assumed that approximately one-third of a building's contents will be in the basement. For 2-story structures, the 60/40 first/second-story split was used, resulting in a contents distribution of 33 percent in the basement, 40 percent on the first floor, and 27 percent on the second.

The adjusted contents curve for "two-floor with basement" (resulting from the modification of the "first floor only" FIA curve) is given in Figure 5.5. At –4 feet (the lowest point on the FIA curve), it is assumed that basement contents (33 percent of total contents) are a total loss. The remainder of the curve simply reflects the addition of the basement losses. As shown, the curve reaches its maximum of about 93 percent at 10 feet. To adjust the multi-story curve, the slope of the original curve was applied, using the 33 percent basement damage as the y-intercept. The resulting curve, also shown on Figure 5.5, reaches about 75 percent at 8 feet (total loss of basement and first floor contents), and 100 percent at 13 feet (total loss of all contents when water is about 4 feet above the second floor.

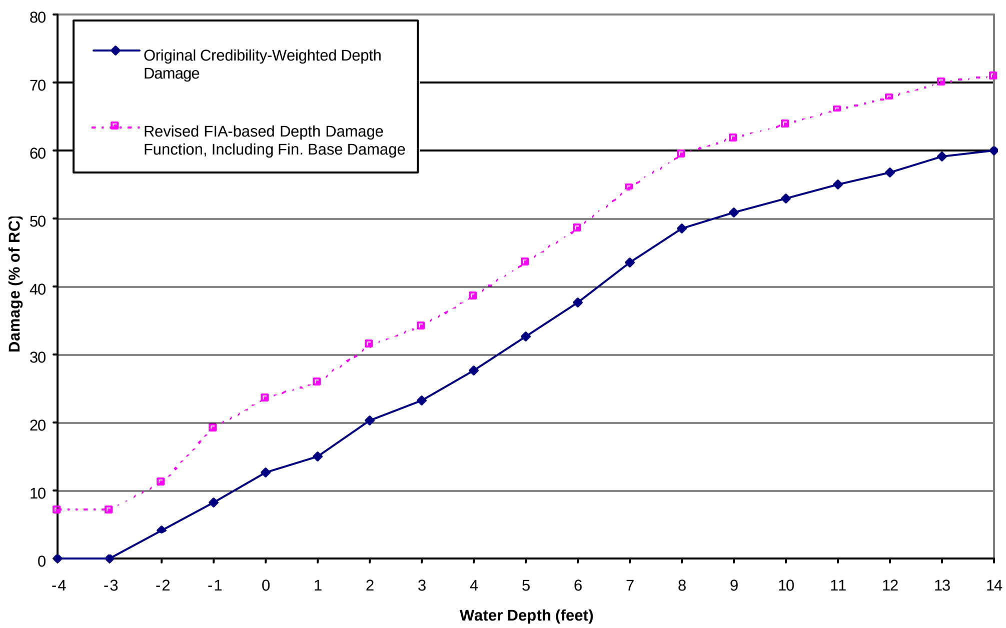

Figure 5.3 FIA-Based Structure Depth-Damage Curve 2 or More Stories, Basement-Modified

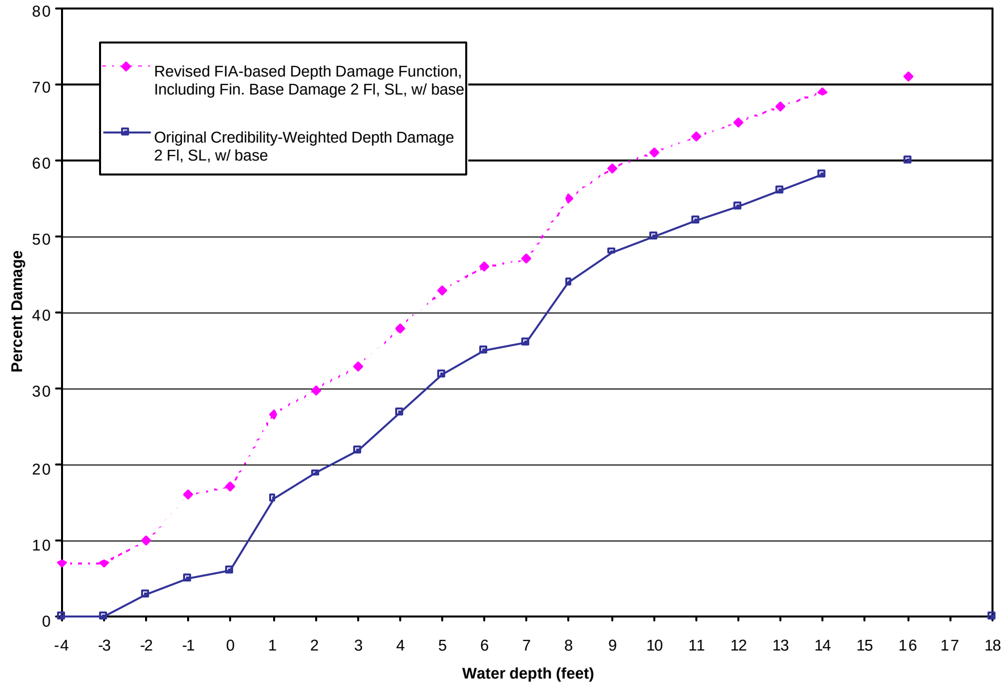

Figure 5.4 FIA-Based Structure Depth-Damage Curve Split Level, Basement-Modified

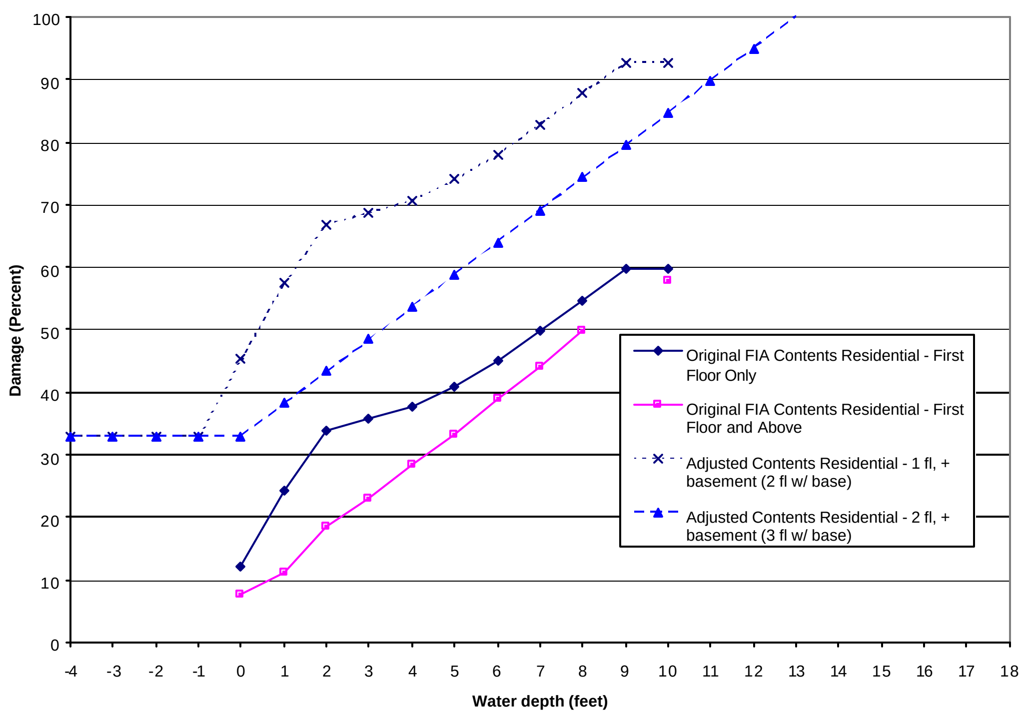

Figure 5.5 FIA-based Residential Contents Damage Curves

5.3.1.2 FIMA (FIA) Residential Depth-Damage Curves – Coastal

In addition to the riverine (non-velocity zone) depth-damage functions, the FIA has developed depth-damage curves appropriate to velocity zones, designated as V-zone curves by the FIA. These curves are applicable to areas subject to three-foot wave action associated with 100-year flood events. Three curves each are available for estimating structure and contents damage; "no obstruction," "with obstruction," and "combined." The obstruction designation refers to the "possible presence of machinery, equipment or enclosures below the elevated floor" (H. Leikin, 1987).

5.3.1.3 USACE Depth-Damage Curves (Residential and Non-Residential)

5.3.1.3.1 Chicago District

The Chicago District developed seven sets of generic structure and content damage functions to represent commercial, industrial and public occupancies in conjunction with the 1996 Feasibility Study on the Upper Des Plaines River in northeast Illinois. These damage functions, based on models developed by the Baltimore and Galveston Districts, classify structures as low, mid and high structure vulnerability, and low, mid and high contents vulnerability, resulting in seven curves representing the various ranking combinations. In addition, seven residential damage functions (1-story, 2-story, split-level with and without basement, and mobile home) were also provided.

5.3.1.3.2 Galveston District

The Galveston District has numerous damage functions, including residential, and more than 145 different non-residential flood damage functions (IWR 85-R-5). These non-residential damage functions include damage to the structure, as well as to its inventory and equipment. The damage functions are based on flood damage records, as well as post-event surveys, including surveys following Hurricane Claudette in 1979. The damage curves are currently used by Galveston and other Districts, including Tulsa and Fort Worth, and are applicable to fresh-water flooding, under slow-rise, slow-recession conditions, with little velocity. In addition, the functions are based on damage to structures without basements, as structures along the Texas Coastal Plain are built without basements because of the high water table.

5.3.1.3.3 New Orleans District

The New Orleans District has developed expert opinion damage functions for the flood control feasibility study in Jefferson and Orleans Parishes (GEC, 1996), and for the Lower Atchafalaya Re-evaluation (GEC, 1997). Depth-damage functions include residential and non-residential structure and contents damage for four types of flooding:

- Hurricane flooding, long duration (one week), salt water
- Hurricane flooding, short duration (one day), salt water

- Riverine or rainfall flooding, long duration (two or three days), freshwater

- Riverine or rainfall flooding, short duration (one day or less), freshwater

Residential structures are classified by number of stories (one, two, or mobile home), and by foundation (piers or slab). Commercial structures are classified according to material and typical configuration (metal frame, masonry bearing, wood or steel frame). In addition, non-residential contents damage functions are provided for a variety of occupancies:

- Eating/recreation – restaurants, bars, bowling alleys, theatres, etc.

- Groceries/gas stations – grocery stores, bakeries, liquor stores, gas stations, convenience stores, etc.

- Multi-family residences – garden apartments, high-rise apartments, condos, etc.

- Professional businesses – banks, offices, medical offices, funeral homes, etc.

- Public/semi-public – schools, government facilities, utility companies, etc.

- Repairs & home use – auto repair, watch repair, reupholstery, home repair, etc.

- Retail & personal - department stores, furniture stores, clothing stores, barbershops, laundromats, etc.

- Warehouse & contractor services - warehouses, manufacturers, etc.

Structures are assumed to be "no basement" structures, as damage curves typically begin at –1 foot of water, and the reference point for water depth appears to be the top of the finished floor, based on review of detailed component loss tables.

5.3.1.3.4 New York District

As part of the Passaic River Basin studies, the New York District developed a variety of residential and non-residential structure and contents damage functions, for structures with and without basements. Also included in the damage functions are models for 10 utility facilities, such as electric power substations, pump houses, and water treatment plants.

Residential damage functions include bi-level, cape, colonial, mobile home, split, two-family and other types. Commercial structures are handled with one damage function, while for contents assessment; the occupancies are organized into 10 different groups. For commercial facilities, both structure and contents damage functions consider the presence of a basement. In addition, there are 35 different industrial damage functions.

5.3.1.3.5 Philadelphia District

The U.S. Army Corps of Engineers Philadelphia District published coastal depth-damage curves as part of a 1991 study entitled "Delaware Coast From Cape Henlopen to Fenwick Island, Delaware; Reconnaissance Study Report." The depth-damage curves consider various structural characteristics, including location (A-zone vs. V-zone), height (1-, 1.5-, and 2-story), foundation (structures on piles and not on piles), and construction material for structure not on piles (wood frame, concrete block, or masonry). The curves were based on "previous studies of similar areas and FIA curves" and predict damage to both structures and contents. However, these studies are not documented and the Corps no longer uses the approach laid out in the Delaware Coast report. As such, the Delaware curves are included herein solely as an example data set, and are not relied upon for the development of HAZUS damage evaluation methodology.

5.3.1.3.6 St. Paul District

The St. Paul District has estimated damage to the Grand Forks area as part of a flood control project, as documented in "General Reevaluation Report and Environmental Impact Statement" (1998). The depth-damage functions used in that report include residential and non-residential functions, whose source is the Vicksburg District. All non-residential uses, including commercial, professional (e.g., offices), industrial, public, semi-public (e.g., churches), recreation, and warehouses are represented by one single damage function.

It should be noted that these damage functions are identified as "no basement." For the Corps' Grand Forks application, it appears that the Corps essentially shifted the damage curve to the left for structures with basements, allowing damage to occur at lower water depths.

5.3.1.3.7 Wilmington District

The Wilmington District provided 13 residential structure and contents damage functions, and 49 non-residential structure functions which may be applied to contents using a contents-to-structure value ratio, as well as a number of damage functions reflecting erosion. The residential damage functions consider structure size (1-, 1.5-, and 2-story, split-level, and mobile home), and configuration (basement, no basement, high-raised, high-raised with ½ living area below). Non-residential classes include: apartments, appliances, auto dealership, auto junk yard, auto parts, bait stand, bank, barber shop, beauty shop, boat stalls, book store, bowling alley, business, church, cleaners, clinic (medical), clothing, dentist office, department store, doctor's office, drug/super, funeral home, furniture, garage, halls, hardware, hotel, jewelry, laundry, liquor, lumber, market/super, market/drive, motel, newspaper, office building, post office, private club, restaurant, rest home, school, service station, theater, theater (drive-in), TV station, tavern, variety store, wash-a-teria, and warehouse.

5.3.1.3.8 USACE Institute for Water Resources (IWR)

The USACE Institute for Water Resources (IWR) is working on a compilation project of "past flood damage surveys" with the identified objective of compiling residential and business damage functions and content valuation functions. The outcome of this study will be a set of recommended depth-damage functions for use throughout the Corps (e.g., a national standard). To date, the only model that has been finalized is for single family residential structures, without basements (IWR concluded that available data on basement damage are insufficient to develop statistical functions at this time.). The IWR recommended structure and contents model for single family residential structures (no basement) is included in the HAZUS damage function library.

5.3.1.4 Other Coastal Depth-Damage Functions

The Tampa Bay Regional Planning Council as part of a 1988 contingency planning study developed additional coastal depth-damage functions. Depth-damage curves (or "loss coefficients") based on historic property damage were presented. These relationships consider structure location (A-zone vs. V-zone) and use (single family, multi-family, mobile home, commercial, industrial, and non-residential). No contents damage functions were presented.

5.3.2 Default Structure and Contents Damage curves

Default curves to estimate structure and contents damage for Level 1 analyses have been selected for each HAZUS$^{®MH}$ occupancy class, for conditions of riverine and coastal flooding. These curves are identified in Tables 5.3 and 5.4. It should be noted that the default riverine damage functions for residential structures with basements have been modified from the original FIA relationship (which reflects FIMA (formerly FIA) policy exclusions) to reflect total damage. The modification is documented in Section 5.3.1.1.1.

Table 5.3 Default Damage Functions for Estimation of Structure Damage

HAZUS Occ. Class	Flooding Type/Zone	Curve Source	Curve Description
RES1	Riverine/ A- Zone	FIA "credibility-weighted" depth-damage curves (CWDD)	1 floor, no basement 2 floor no basement 2 floor, split level, no basement
	Riverine/ A- Zone	Modified FIA CWDD:	EQE-modified versions of FIA CWDD: 2 floor, w/ basement 2 floor, split level, w/ basement
	Coastal/ V- Zone	FIA V-Zone Damage function	Combined curve (average of with and without obstruction)
	Coastal/ A- Zone	FIA V-Zone Damage function	Combined curve (average of with and without obstruction)
RES2	All Zones	FIA CWDD	Mobile home
RES3	All Zones	USACE – Galveston*	Apartment

Notes:

* *All depth-damage curves developed by the USACE Galveston District are assumed to represent structures with no basement.*

Table 5.3 Default Damage Functions for Estimation of Structure Damage (Continued)

HAZUS Occ. Class	Flooding Type/Zone	Curve Source	Curve Description
RES4	All Zones	USACE – Galveston	Average of “Hotel” and “Motel Unit”
RES5	All Zones		No RES5 curves available – use RES6
RES6	All Zones	USACE – Galveston	Nursing Home
COM1	All Zones	USACE – Galveston	Average of 47 retail classes
COM2	All Zones	USACE – Galveston	Average of 22 wholesale/warehouse classes
COM3	All Zones	USACE – Galveston	Average of 16 personal and repair services classes
COM4	All Zones	USACE – Galveston	Average of “Business” and “Office”
COM5	All Zones	USACE – Galveston	Bank
COM6	All Zones	USACE – Galveston	Hospital
COM7	All Zones	USACE – Galveston	Average of 4 medical office/clinic classes
COM8	All Zones	USACE – Galveston	Average of 15 entertainment & recreation classes
COM9	All Zones	USACE – Galveston	Average of 3 theatre classes
COM10	All Zones	USACE – Galveston	Garage
IND1	All Zones	USACE – Galveston	Average of 16 heavy industrial classes
IND2	All Zones	USACE – Galveston	Average of 14 light industrial classes
IND3	All Zones	USACE – Galveston	Average of 10 food/drug/chemical classes
IND4	All Zones	USACE – Galveston	Average of 4 metals/mineral processing classes
IND5	All Zones		No IND5 curves available – use IND3
IND6	All Zones	USACE – Galveston	Average of 8 construction classes
AGR1	All Zones	USACE – Galveston	Average of 3 agricultural classes
REL1	All Zones	USACE – Galveston	Church
GOV1	All Zones	USACE – Galveston	Average of “City Hall” and “Post Office”
GOV2	All Zones	USACE – Galveston	Average of “Police Station” and “Fire Station”
EDU1	All Zones	USACE – Galveston	Average of “School” and “Library”
EDU2	All Zones	USACE – Galveston	Average of “School” and “Library”

Notes:

* *All depth-damage curves developed by the USACE Galveston District are assumed to represent structures with no basement.*

Table 5.4 Default Damage Functions for Estimation of Contents Damage

HAZUS Occ. Class	Flooding Type/Zone	Curve Source	Curve Description
RES1	Riverine/ A- Zone & Coastal/ A- Zone	FIA "credibility-weighted" depth-damage curves (CWDD)	Residential contents – 1st floor only (for 1 floor, no basement) Residential contents – 1st floor and above(for 2 floor no basement, and 2 floor, split level, no basement)
	Riverine/ A- Zone	Modified FIA CWDD:	EQE-modified versions of FIA CWDD: Residential contents – 1st floor and above (for 2 floor, w/ basement, and 2 floor, split level, w/ basement)
	Coastal/ V- Zone	FIA V-Zone Damage function	Combined curve (average of with and without obstruction)
RES2	All Zones	FIA CWDD	Contents – Residential – Mobile Home
RES3	All Zones	USACE – Galveston *	Apartment contents
RES4	All Zones	USACE – Galveston	Average of "Hotel – Equipment" and "Motel Unit - Inventory"
RES5	All Zones		No RES5 curves available – use RES6
RES6	All Zones	USACE – Galveston	Nursing Home –Equipment
COM1	All Zones	USACE – Galveston	Average of 47 retail classes – equipment and inventory, when available
COM2	All Zones	USACE – Galveston	Average of 22 wholesale/warehouse classes – equipment and inventory, when available
COM3	All Zones	USACE – Galveston	Average of 16 personal and repair services classes – equipment and inventory, when available
COM4	All Zones	USACE – Galveston	Average of "Business – inventory" and "Office, equipment"
COM5	All Zones	USACE – Galveston	Average of Bank inventory and equipment
COM6	All Zones	USACE – Galveston	Average of Hospital inventory and equipment
COM7	All Zones	USACE – Galveston	Average of 4 medical office/clinic classes, inventory and equipment, when available
COM8	All Zones	USACE – Galveston	Average of 13 entertainment & recreation classes, inventory and equipment, when available
COM9	All Zones	USACE – Galveston	Average of 3 theatre classes, equipment
COM10	All Zones	USACE – Galveston	Garage, inventory
IND1	All Zones	USACE – Galveston	Average of 16 heavy industrial classes, inventory & equipment, when available

Notes:

* *All depth-damage curves developed by the USACE Galveston District are assumed to represent structures with no basement.*

Table 5.4 Default Damage Functions for Estimation of Contents Damage (Continued)

HAZUS Occ. Class	Flooding Type/Zone	Curve Source	Curve Description
IND2	All Zones	USACE – Galveston	Average of 14 light industrial classes, inventory & equipment, when available
IND3	All Zones	USACE – Galveston	Average of 10 food/drug/chemical classes, inventory & equipment, when available
IND4	All Zones	USACE – Galveston	Average of 4 metals/mineral processing classes, inventory & equipment, when available
IND5	All Zones		No IND5 curves available – use IND3
IND6	All Zones	USACE – Galveston	Average of 8 construction classes, inventory & equipment, when available
AGR1	All Zones	USACE – Galveston	Average of 3 agricultural classes, inventory & equipment, when available
REL1	All Zones	USACE – Galveston	Average of "Church" inventory and equipment
GOV1	All Zones	USACE – Galveston	Average of "City Hall" and "Post Office" equipment
GOV2	All Zones	USACE – Galveston	Average of "Police Station" equipment and "Fire Station" inventory
EDU1	All Zones	USACE – Galveston	Average of "School," Equipment and "Library," Inventory
EDU2	All Zones	USACE – Galveston	Average of "School," Equipment and "Library," Inventory

Notes:

- *All depth-damage curves developed by the USACE Galveston District are assumed to represent structures with no basement.*

5.3.2.1 Commentary on the Assignment and Implementation of Coastal Damage Functions

Several recent studies point to the need for distinguishing between coastal A-zones and riverine A-zones. While the dominant form of damage to buildings in the latter is inundation, buildings in coastal A-zones are often subject to more severe flood forces. Recent post-disaster building damage assessments in coastal areas have shown buildings in coastal A-zones are often damaged by waves, high velocity flows, scour and erosion, and floating debris. Conditions in coastal A-zones are probably closer to those in V-zones than non-coastal A-zones. This observation is supported by FEMA-sponsored laboratory tests of breakaway wall failures. The tests found typical wood frame wall panels fail under wave conditions much less severe than the 3-foot wave that presently divides V-zones and coastal A-zones. Finally, FEMA's newly revised Coastal Construction Manual introduces the coastal A-zone as a flood hazard zone distinct from the non-coastal A-zone. Design and construction recommendations for coastal A-zones are similar to those required for V-zones. Accordingly, FIA V-Zone damage functions have been selected as the default damage function for single-family residential structures in coastal A- zones as well as coastal V-zones.

While the importance of reflecting the differences between coastal and riverine flooding damage is recognized, well-documented coastal damage functions are available only for the RES1 occupancy category (single family homes). However, since single-family dwellings make up the majority of the coastal exposure in the default database, this assumption is deemed adequate. The USACE Galveston non-residential damage functions have been selected as defaults in both riverine and coastal areas, until more detailed non-residential coastal damage functions become available.

In general, A-zone and V-zone depth-damage curves define water depth differently.

- In A-zones (non-velocity zones), the water depth is relative to the top of the finished flooring of the lowest floor, excluding the basement.

- In V-zones, the water depth is relative to the bottom of the floor beam of the lowest floor.

This variation in reference depth requires that particular attention be paid to both default distributions of foundations and their associated height above grade in Level 1, and individual building elevations being analyzed in Level 2 analyses.

The HAZUS®*MH* Flood Model addresses direct damage to buildings and their contents. Readers are referred to the recent Heinz Center (2000) report – ***The Hidden Costs of Coastal Hazards: Implications for Risk Assessment and Mitigation*** – for an expanded discussion of direct costs and other costs associated with coastal flood disasters.

5.4 Building Damage Due to Velocity

Flooding with significant velocity can result in structure and content damage in addition to the damage caused by simple inundation. The USACE notes that velocity is a "… major factor aggravating structure and content damage…" and that the "… additional force creates greater danger of foundation collapse and forceful destruction on contents" (USACE, 1996).

The relationship between velocity and damage has been addressed in a number of models and methods. For example, the Ontario Ministry of Natural Resources provides the following guidelines (OMNR, 1997) for structures:

> "Structural Integrity (structures above ground) **-** A depth of 0.8m is the safe upper limit for the above ground/super structure of conventional brick veneer, and certain types of concrete block buildings. The structural integrity of elevated structures is more a function of flood velocities (e.g., erosion of foundations, footings or fill) than depth. The maximum permissible velocity depends on soil type, vegetation cover and slope but ranges between 0.8-1.5m/s *(2.62 ft/sec – 4.92 ft/sec)*".

Within the HAZUS flood model, velocity-based building collapse curves developed by the Portland District of the U.S. Army Corps of Engineers have been utilized (except for manufactured housing). These curves (as provided in IWR 85-R-5, 1985) relate collapse potential (e.g., collapse or no collapse) to overbank velocity (in feet per second) and water depth (in feet) for three building material classes (wood frame, steel frame, and masonry or concrete bearing wall structures). The Portland collapse curves for wood frame, masonry and steel frame are given in Figures 5.6, 5.7 and 5.8, respectively.

For application within the flood model, it has been assumed that below velocities of 2 feet per second, collapse potential is extremely low and damage is due to inundation only. Further, the "masonry and concrete bearing wall" model is applied to both the concrete and masonry HAZUS building types.

For manufactured housing (MH), velocity damage curves are based on information developed by FEMA (FEMA, 1985), relating velocity and depth to drag forces. Based on information provided within that document, it is assumed that drag forces exceed MH design capacity at around 13 pounds per linear foot of home length, and it is possible to determine the relationship between depth and velocity for this threshold level of drag force. This results in a simpler velocity damage function for MH than for the other material types; for a given depth, if the velocity equals or exceeds the collapse velocity, the structure is assumed to collapse.

Velocity-depth damage functions as implemented within HAZUS are provided in Tables 5.5 through 5.8 for building types wood, masonry and concrete, steel, and manufactured homes, respectively. These functions relate velocity and depth to collapse potential. If it is determined that a given building or building type collapses, the building is assumed to be a total loss, and the percent damage is reset to 100. If the model indicates that the velocity does not lead to collapse, damage is estimated based on inundation levels only.

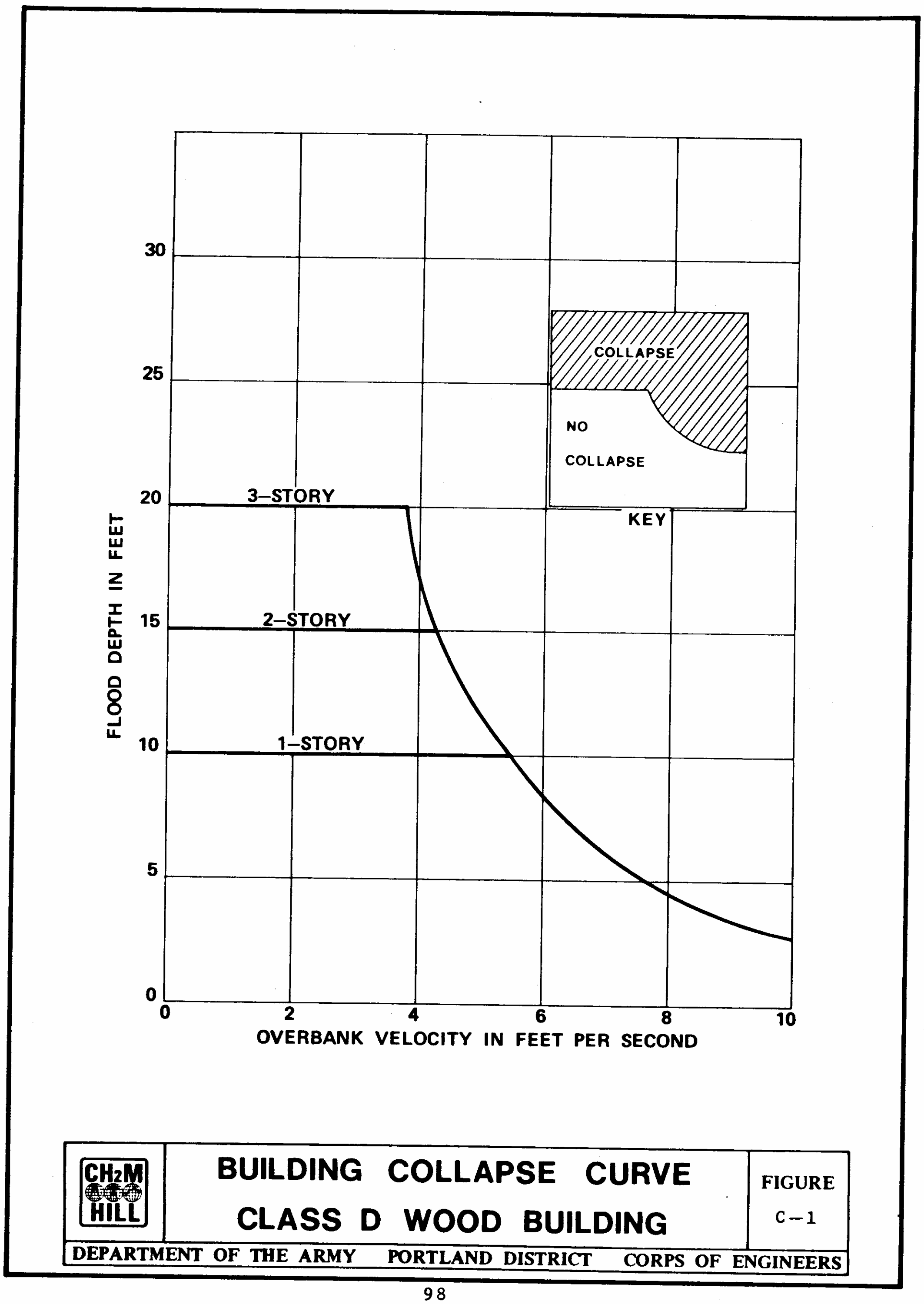

Figure 5.6 Building Collapse Curve for Wood Frame Buildings developed by the USACE Portland District (USACE, 1985)

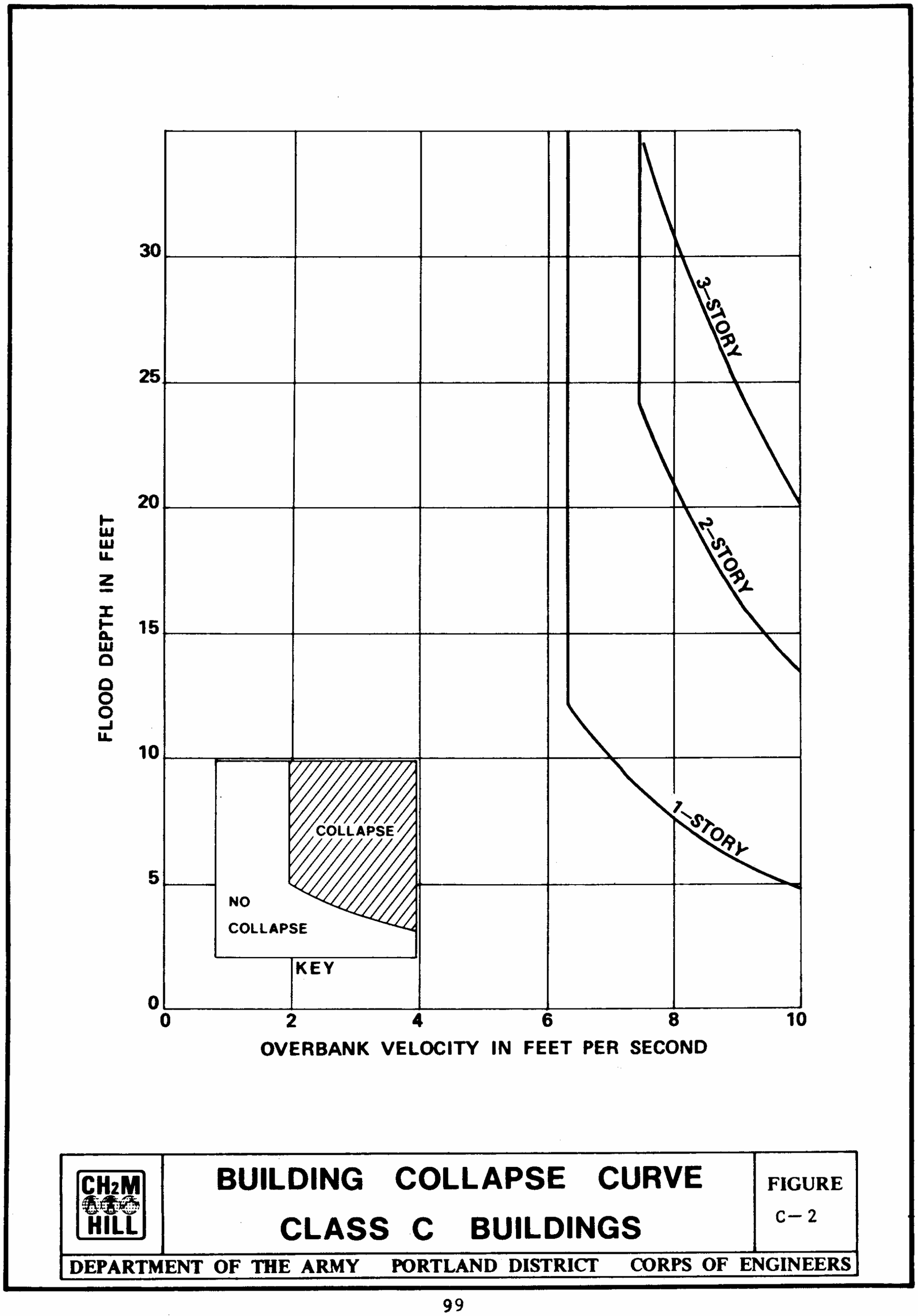

Figure 5.7 Building Collapse Curve for Masonry and Concrete Bearing Wall Buildings developed by the USACE Portland District (USACE, 1985)

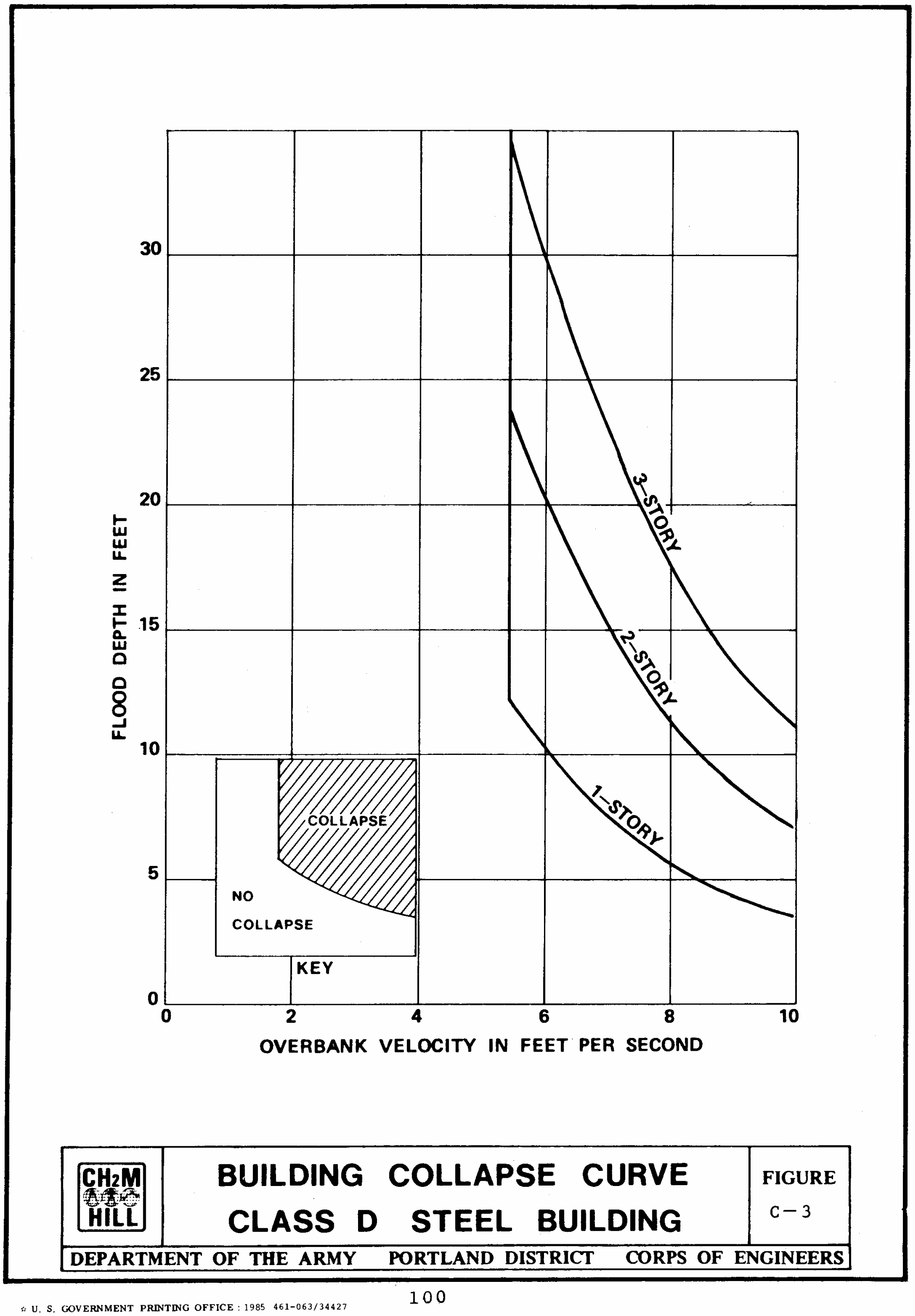

Figure 5.8 Building Collapse Curve for Steel Frame Buildings developed by the USACE Portland District (USACE, 1985)

Table 5.5 Velocity-Depth Damage Relationship for Wood Buildings

Material	# Stories (hgt)	Depth Threshold in feet DT(hgt)	Velocity Threshold in feet/sec VT(hgt)	Collapse Potential			
				V < 2 fps any Depth	V < VT(hgt) D < DT(hgt)	V < VT(hgt) D >= DT(hgt)	V >= VT(hgt) any Depth
Wood	1 story	10	5.34	no collapse	no collapse	collapse	collapse if $D > 268.38V^{-1.9642}$
Wood	2 story	15	4.34	no collapse	no collapse	collapse	collapse if $D > 268.38V^{-1.9642}$
Wood	3 story	20	3.75	no collapse	no collapse	collapse	collapse if $D > 268.38V^{-1.9642}$
Wood	4+ stories			no collapse	no collapse	no collapse	no collapse

Table 5.6 Velocity-Depth Damage Relationship for Masonry and Concrete Buildings

Material	# Stories (hgt)	Velocity Threshold in feet/sec VT(hgt)	Collapse Potential		
			V < 2 fps	V < VT(hgt)	V >= VT(hgt)
Masonry & Concrete	1 story	6.31	no collapse	no collapse	collapse if $D > 525.09V^{-2.0406}$
Masonry & Concrete	2 story	7.47	no collapse	no collapse	collapse if $D > 1210.6V^{-1.9511}$
Masonry & Concrete	3 story	9.02	no collapse	no collapse	collapse if $D > -4.8864V+69.086$
Masonry & Concrete	4+ stories		no collapse	no collapse	no collapse

Table 5.7 Velocity-Depth Damage Relationship for Steel Buildings

Material	# Stories (hgt)	Velocity Threshold in feet/sec VT(hgt)	Collapse Potential		
			V < 2 fps	V < VT(hgt)	V >= VT(hgt)
Steel	1 story	5.40	no collapse	no collapse	collapse if $D > 0.3125V^2 - 6.6875V + 39.125$
Steel	2 story	5.40	no collapse	no collapse	collapse if $D > 0.5808V^2 - 12.595V + 74.859$
Steel	3 story	5.40	no collapse	no collapse	collapse if $D > 0.7737V^2 - 17.112V + 104.89$
Steel	4+ stories		no collapse	no collapse	no collapse

Table 5.8 Velocity-Depth Damage Relationship for Manufactured Housing

Flood Depth (ft) relative to top of finished floor	Collapse velocity (fps)
-0.9	11.08
-0.5	4.52
0.0	3.20
0.5	2.61
1.0	2.26
1.5	2.02
2.0	1.85
3.0	1.60
4.0	1.43
5.0	1.31
6.0	1.21
7.0	1.13
8.0	1.07
9.0	1.01
10.0	0.96
11.0	0.92
12.0	0.89

5.5 Consideration of Warning and Associated Damage Reduction

Information detailing the implementation of damage reduction was obtained from the IWR and the USACE New York District. The following publications were received and reviewed to identify applications within HAZUS$^{®MH}$ for damage reduction based on flood warning:

- URS Consultants, Inc. (1992), “Updated Flood Damage Evaluation Guidelines for the Passaic River Basin Project,” prepared by URS Consultants for the USACE New York District.

- URS Consultants, Inc. (1992), “Passaic River Basin Economic Updates – Sample Selection Requirements,” prepared by URS Consultants for the USACE New York District.

- USACE (1994), “Framework for Estimating National Economic Development Benefits and Other Beneficial Effects of Flood Warning and Preparedness Systems,” IWR Report 94-R-3, March 1994.

- USACE (1984), “Flood Emergency Preparedness System: Passaic River Basin, New Jersey and New York, Detailed Project Report and Environmental Assessment,” USACE New York District.

This material was reviewed to identify applications within HAZUS for damage reduction related to flood warning. The work done by the New York District models the effectiveness of a flood warning system through the modification of the Day curve, for conditions specific to the Passaic River basin. Harold Day, in a series of publications in the late 1960's, developed a method that introduced the consideration of warning time to the depth-damage relationship. Application of the methodology resulted in several curves that relate damage reduction to forecast lead time, defined as the time required for warning dissemination and effective public response. The Day curve based on a scenario of riverine flooding in residential areas is presented as Figure 5.9.

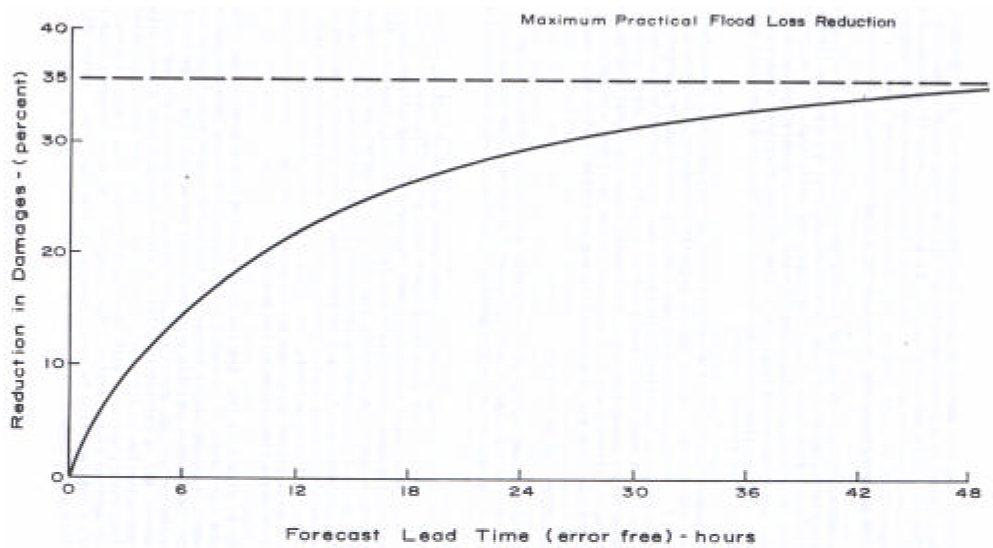

Figure 5.9 Day Curve for Residential Areas (Source: USACE, New York District, 1984)

The original Day curve indicates a maximum loss reduction of 35% of total damage (e.g., structure and contents), and assumes a public response rate of 100%. A response rate of 100% is not likely in all circumstances, and as such, the New York district modified this and some other of the major lead time assumptions inherent in the Day curve:

1. Building location – Forecast lead-time will vary at each building, based on water velocity, storm type (riverine or flash), basin time of concentration, and structure elevation. These variables were considered to develop a mean forecast lead-time for the Passaic River basin, defined as the average time available for public response.

2. Warning dissemination – The speed of warning dissemination is affected by several factors, including the dissemination medium (TV, radio, siren, etc.), time of day, source, and content. As such, the public will receive the flood warning at varying times. The New York District used this understanding to develop distributions of warning dissemination.

3. Public response – Once the warning is disseminated, all residents will not respond with damage reduction activity at the same rate. Research has shown that the public response rate is conditioned upon demographic factors, such as age, income, ethnicity, and past experience with floods. The District used the results of a literature review to develop a public response time distribution, which was capped at a rate of 85%.

The work performed by the New York District improved upon the original Day curve producing a modified curve that was tailored to conditions in the Passaic River basin. While a few select sophisticated users could modify the Day curves in a fashion similar to the New York District, most will not have the expertise. Accordingly, the implementation of damage reduction from warning within HAZUS®MH will be based on the generalized Day curve shown in Figure 5.9, and will allow the user to make a few simple modifications, as follows:

- The user must enter warning time in hours (default is no warning, and accordingly, no damage reduction).

- The default assumption for the maximum reduction in damage to contents (and inventory) will be set at 35 percent, varying as shown on the Day Curve. The user will have the option to adjust the maximum damage reduction, and the software will automatically scale the damage reduction function accordingly.

- The user may opt to apply the damage reduction factor to structure damage (in addition to contents damage), if flood-fighting efforts (e.g., sandbagging, etc.) are considered significant. As with contents and inventory, the user will have the option to adjust the maximum damage reduction up to a maximum of 35%.

- The user will have the option of applying a damage reduction factor to vehicles. The user must specify the percent of vehicles (0 – 100%) removed from the floodplain as a result of the warning.

It should be noted that the use of the original Day curve as the basis for modeling the effect of warning time on the depth-damage relationship, is not the most accurate method available. IWR Report 94-R-3 expands upon this point:

> The Day curve methodology is perfectly applicable today. The actual Day curves, however, should not be used. The Day curve methodology was surely a pathfinding work at the time, but continued use of curves based on the contents of a typical house in the early 1960s likely do not apply to current floodplain situations.

Even given this deficiency, the Day curves appear to be the best currently available source for use as a nationally applicable default data set.

5.6 Consideration of Uncertainty

The HAZUS®MH flood model, like the earthquake model, does not address uncertainty. While the importance of the consideration of uncertainty is widely acknowledged, it has not been addressed in the current version of HAZUS. Therefore, model results should not be considered exact figures, and should be used accordingly. Nevertheless, it is the belief of the Flood Committee that planning decisions made with the benefit of model results will be better than decisions made without any consideration of science.

5.7 Guidance for Expert Users

5.7.1 Selection of Alternate Depth-Damage Functions

The flood model provides the user with the opportunity to compare and select alternative depth damage functions from the extensive library of functions within the model. The user can identify and select the damage function they would prefer to use in the estimation of damage to buildings of any occupancy class.

5.7.2 Sources of Additional Depth-Damage Functions

Additional depth-damage functions may be available from local USACE Districts or floodplain managers and may include depth-damage relationships developed from post-flood surveys. Users can also develop custom depth-damage functions reflecting the unique characteristics of their community.

5.7.3 Development of Custom Depth-Damage Functions

The user can develop a new damage function using features within the model. The user would create the damage function in the Building Damage Function menu and save the function under a name provided by the user. The user would then assign the newly-developed damage function to the occupancy class of interest.

5.7.4 Evaluating the Beneficial Functions of Natural Floodplains

The current HAZUS flood model does not include quantification of the benefits of flooding. However, there are a number of methods available for users interested in benefits estimation. The following discussion identifies a variety of benefits associated with floodplains, and discusses methods available for their quantification.

5.7.4.1 Beneficial Functions of Natural Floodplains

In recent years, there has been growing interest in more detailed and accurate assessment of the beneficial functions of floodplains to support floodplain management decision-making (Kusler, 1997). Undeveloped and evacuated floodplains provide a number of valuable functions to society, which have historically been overlooked. The major functions include attenuation of flood flows, maintenance of high soil and water quality, water supply, wildlife habitat, and recreational opportunities.

5.7.4.1.1 Flood Attenuation

Undeveloped floodplains help attenuate flooding through the absorption and storage of floodwaters. Floodplains also help reduce flood velocity because friction factors are much higher in the floodplain than in the main channel. The velocity reduction reduces erosion and allows for the deposition of sediment. The construction of flood control projects such as levees, floodwalls, and channel modifications result in decreased floodway width and increased hydraulic conveyance. Such structural remedies are designed to protect areas previously located in the historic floodway and quickly pass floods downstream. However, they also serve to separate the river from its floodplain, eliminating the flow management services provided by floodplain wetlands. The resulting increases in flow rates, flood depths, and sediment loads often increase the costs of flood damages for downstream communities and property owners. In coastal areas, wetlands can form a buffer between development infrastructure and hurricanes and other storm surges. Coastal wetlands absorb enormous amounts of water and dissipate wave energy that would otherwise allow storms to do severe damage inland (LCWCRTF, 1997). The flood attenuation value that natural floodplains provide to society is manifested in the following ways:

- Loss reductions in structure, contents, infrastructure, and income
- Cost reductions in emergency response, administration, and health care
- Retarded rate of sediment deposition into lakes, reservoirs, and estuaries

5.7.4.1.2 Soil Quality

As flood flows spread out over a floodplain, nutrient rich sediments are deposited. This deposition can improve soil quality for agricultural and environmental purposes.

5.7.4.1.3 Water Quality

Undeveloped floodplains provide water treatment value by improving water quality. Floodplain plants and soils provide natural water filtering, nutrient uptake, and detoxification of pollutants that would otherwise flow into watercourses (USACE, 1996). Trees growing along the riverbank and in within wetlands provide shade that reduces water temperatures. Studies of polluted waters flowing through wetlands have shown significant reductions in biochemical oxygen demand (BOD), phosphorous, and nitrogen.

5.7.4.1.4 Water Supply

Floodplains are an important setting for groundwater recharge. Riverine floodplains reduce the frequency and duration of low surface flows (maintain base flows) by slowly releasing water stored during flooding (Cowdin, 1999). Water stored through floodplains can be used for agricultural, municipal, industrial purposes.

5.7.4.1.5 Wildlife Habitat

It has been estimated that nearly 70% of all vertebrate species rely on the floodplain during their life cycle (American Rivers, 2000) for food, shelter, migration, and reproduction. Natural floodplains have a high degree of biological diversity and productivity. River corridors are frequently used as migration avenues for birds; aquatic and wetland areas provide habitats for fish; floodplain trees serve as important nesting habitats.

5.7.4.1.6 Recreational Setting

Floodplains provide the setting for a host of recreational activities, such as swimming, boating, fishing, hunting, hiking, camping, and viewing wildlife.

5.7.4.1.7 Others

There are several other important functions provided by natural floodplains that are not considered further in this paper. Floodplains improve air quality through removal of atmospheric carbon, can moderate temperatures in urban areas, and provide a setting for educational and scientific research activity.

5.7.4.2 Ecological Assessment of Natural Floodplain Functions

The term floodplain is defined by FEMA as any land area susceptible to being inundated by floodwater from any source (FEMA, 2000). Within this broad definition are aquatic, riparian, and wetland sections (Figure 5.10). Aquatic areas are characterized by having standing or moving water at some time during the year, such as streams and lakes, whereas riparian areas border rivers, streams and creeks and typically include the channel banks and the greater floodplains. Wetlands are special aquatic areas that often develop in transitional zones between aquatic and upland habitats, and can occur in riverine, lacustrine, and coastal settings. Wetlands are either permanently or seasonally wet and support specially adapted vegetation and wildlife (Cowdin, 1999).

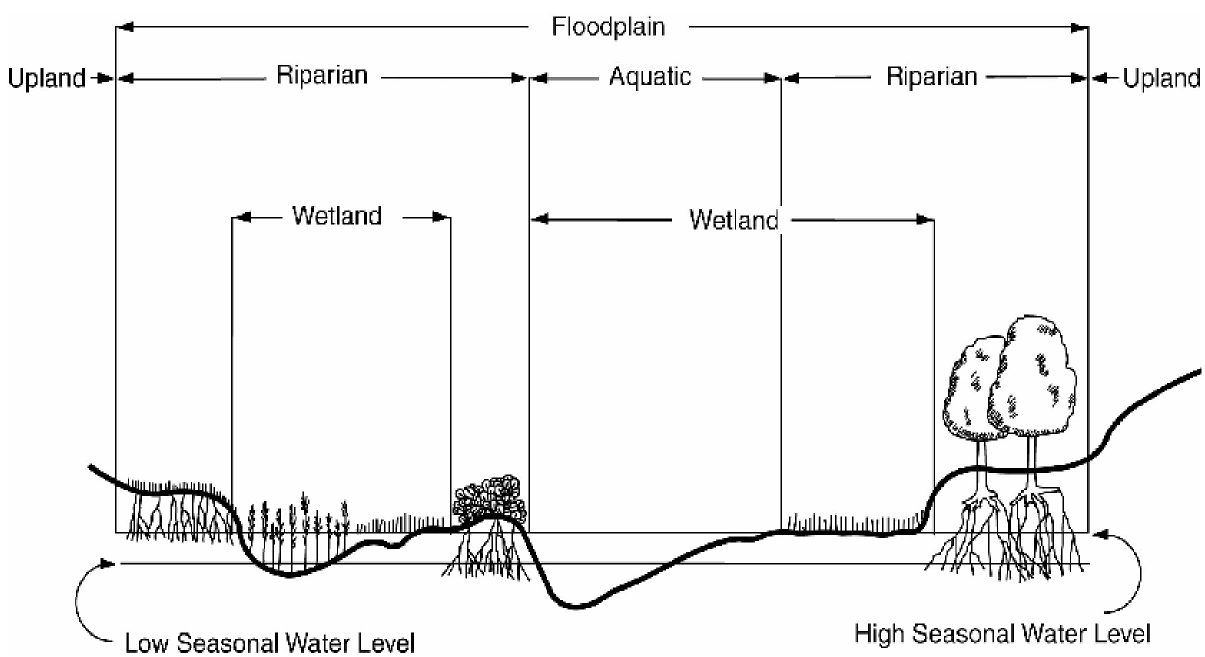

Figure 5.10 Riverine floodplain sections (Source: Cowdin, 1999)

The majority of methods used for the functional assessment of natural floodplains are focused on the evaluation of wetlands. Not all wetlands perform all functions, nor do they perform all functions equally well. Numerous factors, such as the size of a wetland and its location within a watershed, may determine what functions it will perform (Novitski, *et al*., 1996). Several wetland assessment methods have been developed that are used by wetland managers and planners to assign floodplain functions to specific wetlands. Three of these methods are summarized in the following paragraphs.

5.7.4.2.1 Wetland Evaluation Technique

First developed in 1983, the wetland evaluation technique (WET) is designed to evaluate individual wetlands based on their functions. Characteristics such as vegetation, topography, and watershed characteristics are used to estimate whether a wetland has a high, medium, or low probability of performing various functions (Novitski, *et al*., 1996):

- groundwater recharge
- groundwater discharge
- flood flow alteration
- sediment stabilization
- sediment/toxicant retention
- nutrient removal/transformation
- production export
- wildlife diversity/abundance
- aquatic diversity/abundance
- recreation
- uniqueness/heritage

The evaluation is based on the capability and potential of a wetland to perform each function, as well as its societal significance (ecologic and economic). The resulting probability ratings estimate the likelihood of a wetland to perform each function.

5.7.4.2.2 Environmental Monitoring Assessment Program

The environmental monitoring assessment program (EMAP) was created by the U.S. EPA in 1988, with the goal of measuring the condition and trends of many types of ecological resources, such as forests, wetlands, deserts, agricultural systems, and surface waters (EPA, 1997). The wetlands component of the EMAP is designed to identify indicators of wetland condition, standardize measurement protocols, develop indices of condition, and establish a national network for monitoring wetland condition (Novitski, *et al*., 1996). The categories used to assess wetland condition are biological integrity, harvestable productivity, flood reduction and shoreline protection, groundwater conservation, and water quality improvement. Indices of wetland condition relate to one or more of these categories, and are compared to those of the least impacted wetlands in the region, so called reference wetlands.

5.7.4.2.3 Hydrogeomorphic Approach

Hydrogeomorphic (HGM) classification was originally developed in the early 1990s, and is somewhat of a hybrid of the WET and EMAP methodologies. The US Army Corps of Engineers has adopted the approach in order to satisfy requirements of Section 404 of the Clean Water Act. The approach is intended to be regionally-applicable, with the ability both to assess a variety of wetland types and functions, and to assess functions accurately and efficiently within time and resource constraints (Smith, *et al.*, 1995). To apply HGM classification to a given region, the functions performed by wetlands in a specific hydrogeomorphic setting are first identified. The characteristics of a specific wetland are then compared to the characteristics of reference wetlands (Novitski, *et al.*, 1996). This comparison is used to assign a value to each beneficial function. The particular characteristics evaluated are limited to those important to the region and hydrogeomorphic setting.

The WET, EMAP, and HGM methodologies are the primary approaches used for wetland assessment, but are by no means the only ones. Unfortunately, many existing techniques have been plagued by a variety of problems and limitations including high costs, technical expertise needs, and margins of error. Moreover, the methods may provide only a portion of the assessment information needed for specific floodplain management purposes. Overall, these techniques can be used to help assess the natural functions of wetland and broader floodplain areas, but should be approached with care (Kusler, 1997).

5.7.4.3 Economic Valuation Of Natural Floodplain Functions

Floodplains perform a multitude of complex and interrelated functions that provide valuable goods and services to society (Cowdin, 1999). But because of the non-market nature of most floodplain benefits, they are often difficult to quantify. However, several techniques have been developed to measure the economic value of non-market goods and services; they can be grouped into four primary categories: market approaches, indirect market methods, expressed preference models, and benefit transfer.

5.7.4.3.1 Market Approaches

These methods rely on market-determined prices to determine the value of ecosystem goods that are sold in organized markets.

- *Direct Market Price Method* – current or past market prices are used to assign value to goods or services. Some examples of floodplain goods sold in the open market include water supply, commercially harvested fish, and wood products.

- *Factor Income/Productivity Method* – the value of a marketed good is measured relative to the change in value of a non-market ecosystem service that serves as a factor of production for the marketed good. The factor income/productivity method relies on estimating and using this production relationship to estimate how changes in an ecosystem will affect the production costs or profits of the marketed good. For example, an increase in soil quality could lead to lower crop production expenses. The resulting increase in agricultural profits could be used as a measure of the soil quality function of an undeveloped floodplain. Weakness: applicable only if the production unit in question is small relative to the overall production of the marketed good, or if the improvement in the ecosystem service represents only a small marginal change (USACE, 1996).

5.7.4.3.2 Indirect Market Methods

These methods infer values for goods and services based on prices observed for other related goods and services (Cowdin, 1999):

- *Avoided Costs* – Avoided costs can be estimated in two ways. In the least cost alternative method, the value of a good or service is measured by assuming that its benefit cannot have a value higher than the alternative costs avoided. For example, the water quality benefit of a floodplain could be measured as the cost of building and operating a water treatment facility. In the property damages avoided method, the benefit of the ecosystem service is estimated based on the dollar value of property damages expected to result from not having the service (assumes no alternative). As an example, consider the justification of a floodplain development regulation. The benefits of flow and velocity reduction could be estimated by the value of avoided property damages.

- *Replacement Costs* – measures the value of a good or service assuming that its benefit cannot have a value higher than the cost of producing the same good or service in another way. For example, the value of preserving habitat in one particular location can be measured by the cost of replacing that habitat (with similar structural and functional characteristics) in another (Cowdin, 1999).

- *Hedonic Pricing* – measures the contributions of various characteristics to the price of a good. For example, the hedonic property value model asserts that the price paid for a property directly reflects environmental attributes such as clean air, beauty, and proximity to wetlands, fishing, and hiking (Farnam, 1999). As such, this method is useful for the value estimation of ecosystem amenities and aesthetics. Strength: actual market prices are used. Weakness: the environmental characteristics must be shown to affect price.

- *Travel Cost* – measures the value for a good or service based upon the costs (time and money) incurred by consumers to obtain that good. This method is typically applied to the measurement of recreational benefits. Strength: allows the use of observed values. Weakness: region-wide modeling is required to estimate impacts of changes in site quality.

5.7.4.3.3 Expressed Preference Models

In this approach, values are determined for ecosystem services directly through expressed preferences in money bids, hypothetical markets, policy referenda, and surveys (USACE 1996).

- *Contingent Valuation Method* – sophisticated surveys are used to estimate willingness to pay for environmental improvement. Strength: can be applied to estimate values for a multitude of ecosystem benefits. Weakness: questions can be misinterpreted and responses can be biased. In short, the results may not be reliable.

5.7.4.3.4 Benefit Transfer

The benefit transfer approach is not really an evaluation model, but rather a way to apply results between studies. Existing non-market values are transferred to a new study which is different from the study for which the values were originally estimated (Farnam, 1999). Strength: estimates can be quickly and cheaply developed. Weakness: the quality of the results depends heavily on the quality of the original study.

Table 5.9 indicates which economic methods are applicable to various functions of natural floodplains. Table 5.10 summarizes the results of previous studies in which monetary values were derived for certain floodplain functions through the application of economic valuation methods.

Table 5.9 Economic Methods for Valuing Natural Floodplain Functions

Natural Floodplain Functions	Valuation Method						
	Market Price Analysis	**Factor Income/ Productivity**	**Avoided Costs**	**Replacement Costs**	**Travel Costs***	**Hedonic Property Pricing***	**Contingent Valuation***
Attenuate Flood Flows		X	X	X		X	X
Maintain Soil Quality	X	X	X	X			X
Maintain Water Quality	X	X	X	X			X
Maintain Water Supply	X	X	X	X			X
Maintain Wildlife Habitats	X	X	X	X	X	X	X
Maintain Air Quality	X	X	X	X		X	X

* Original studies or transfers from other studies.

(Adapted from Cowdin, 1999)

Table 5.10 Summary of Non-market Values ($ 1998)

Activity	Number of Studies	Methodologies	Range	Mean	Units
Camping	24	Travel cost; Contingent valuation	9.10 - 32.5	23.50	$/Day
Picnicking	12	Travel cost; Contingent valuation	6.5 - 52	20.80	$/Day
Biking	2	Travel cost; Contingent valuation	60.20 - 61.38	60.81	$/Day
Boating *	21	Travel cost; Contingent valuation	7.70 - 216.55	51.35	$/Day
Recreational Fishing	4	Travel cost; Contingent valuation	15 - 95.30	55.00	$/Day
Waterfowl Hunting	21	Travel cost; Contingent valuation	27.60 - 113.16	51.51	$/Day
Flood Prevention	3	Hedonic Pricing	5 - 10	7	% of property value
Value of Wetlands	2	Contingent valuation	19.57-251	---	$/respondent

* Motorized and non-motorized boating.

(Adapted from Farnam, 1999)

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