
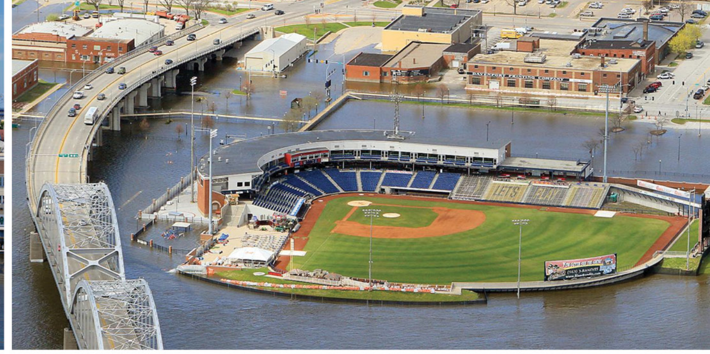



Building Codes Save: A Nationwide Study

Losses Avoided as a Result of Adopting Hazard-Resistant Building Codes

November 2020

FEMA

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Losses Avoided as a Result of Adopting Hazard-Resistant Building Codes

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Executive Summary

Since 1980, the United States has sustained over $1.6 trillion in losses due to natural disasters (NOAA, 2019). The losses have trended upward during this period (see Figure ES-1) because of the escalating frequency and severity of weather-related disasters and the population growth in hazard-prone areas such as the Gulf Coast. Weather-related disasters include floods, hurricanes, tropical storms, tornados, wildfires, droughts, winter storms, and extreme temperatures.

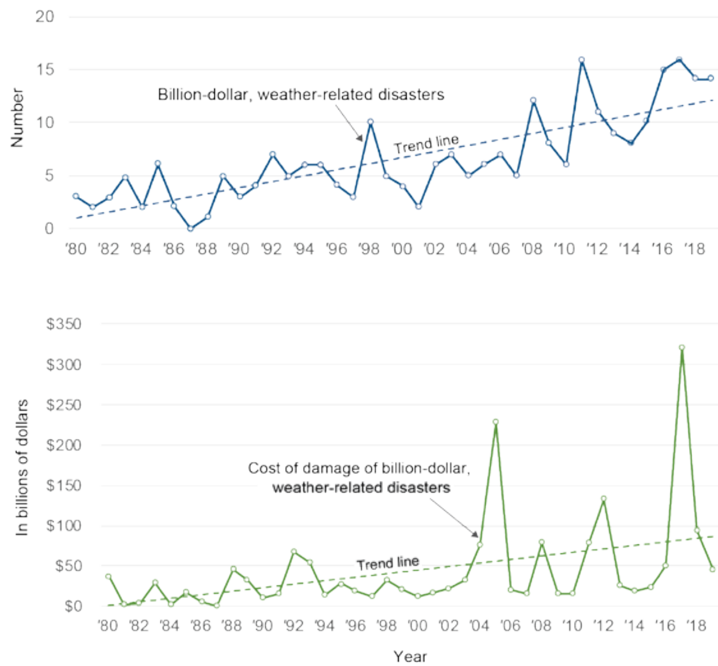

Figure ES-1: Number and cost of billion-dollar natural disasters (drought, flooding, freeze, severe storm, cyclone, wildfire, and winter storm) in the United States, 1980 to 2019, CPI adjusted (NOAA, 2020)

The frequency and magnitude of seismic hazards (earthquakes and tsunamis) and geologic hazards (landslides) have been steady in recent decades, but the population in the areas that are prone to these hazards has continued to grow, increasing the risk of damage.

> *Flooding is by far the most common natural disaster in the United States—90% of natural disasters are floods, and every county in the nation faces some level of flood risk. The overwhelming majority of damage from flooding is to houses.*

Natural disasters are responsible for a broad range of devastating losses: loss of life and injuries; damage to homes, businesses, infrastructure, and the environment; mental trauma; displacement; disruption of normal life; loss of income; and damage to local and regional economies. Some losses are permanent. Recovering the others requires contributions from local, state, and federal governments; volunteer organizations; homeowners; business owners; and the private sector.

The Federal Emergency Management Agency (FEMA) has been working in partnership with local and state governments for decades to reduce losses from natural disasters by developing risk-based hazard maps. The maps help communities reduce risk by planning developments away from high-risk areas and identify locations to adopt risk mitigation measures.

Flood level, Midwest floods of 2008, Cedar Rapids, Iowa (FEMA, 2009a)

FEMA also develops recommendations for making building codes more hazard resistant, largely through FEMA's Mitigation Assessment Teams (MATs). For more than 30 years, MATs have been working with state and local officials to investigate the performance of buildings and infrastructure after disasters, down to the types of nails that are used to join wood framing members and the spacing of the nails. The investigations have shown that strengthening buildings reduces losses (FEMA, 2020d). MAT reports develop recommendations for changes in construction methods based on field investigations and building science research. Priority recommendations are then adapted into building code amendment proposals.

FEMA's advocacy of building codes extends to code adoption by states and communities. For example, the Community Rating System, which is part of FEMA's National Flood Insurance Program (NFIP), is a voluntary incentive program that encourages community adoption of hazard-resistant building codes to exceed the minimum NFIP requirements. The incentive is that the community's flood insurance premiums are discounted.

Overview of the National BCS Study

The findings of the MAT investigations, the magnitude of recent hazard events, and the escalating cost of natural disasters together revealed a compelling need to quantify the value of building codes in reducing damage from natural disasters nationwide.

Multi-family, wood-framed residential building damaged by high winds, Hurricane Katrina, Waveland, Mississippi, 2005 (FEMA, 2006)

In 2011, FEMA initiated a four-phase study, "Building Codes Save: A Nationwide Study – Losses Avoided as a Result of Adopting Hazard-Resistant Building Codes." The pilot and demonstration phases were used to develop the National Methodology for this final phase.

Multi-family, wood, residential building collapse, Loma Prieta earthquake, California central coast, 1989 (FEMA, 2018a)

The BCS Study hypothesis was that communities with significant hazard exposure have realized financial benefits by adopting building codes. The hypothesis was tested by modeling quantifiable losses avoided (i.e., the money that was saved by avoiding physical damage) resulting from the use of building codes.

What makes the BCS Study unique and challenging is the massive amount of local data that had to be collected, filtered, formatted, and analyzed to generate a nationwide picture. Available records of buildings constructed from 2000 through 2016 were evaluated including the building parcels, mapped hazard exposure, and building code histories nationwide, notwithstanding data limitations. The building codes that were evaluated were primarily the International Codes® (I-Codes®), introduced by the International Code Council® in 2000, namely the *International Building Code®* and the *International Residential Code®*.

The losses avoided that were modeled (simulated) were physical damage to buildings and contents. Other types of savings or benefits (e.g., reduced loss of income) and costs (construction cost to adhere to I-Codes) were not modeled.

At its core, the study is a big data analysis that helps answer these important questions:

- How much have the I-Codes (and similar codes) that have been adopted since 2000 saved counties, states, and the nation?
- How do the benefits of commercial and residential building codes differ?
- What percentage of the new building stock in the nation is built to hazard-resistant codes?

Life Safety:
Purpose of Building Codes

The primary purpose of I-Codes is to establish the minimum requirements to protect life safety and reduce property damage up to a design event (a defined risk threshold). The purpose is achieved by promoting the construction of hazard-resistant buildings.

I-Codes are updated every 3 years. Over the last two decades, the updates have increasingly emphasized improving property protection to reduce dollar losses from natural hazard events, which has improved the life safety performance of buildings.

The *International Residential Code* also includes residential affordability as a key consideration.

The goal of the BCS Study is to help inform community officials and the public about the value of adopting the I-Codes to increase resilience against natural hazards.

Methodology

The study methodology is built on FEMA's Hazus multi-hazard loss modeling methodology and software. Hazus provides a consistent framework for modeling the three dominant hazards in the areas where these hazards are the most prevalent: (1) floods in every state and Washington, DC, (2) hurricane wind in the 22 hurricane prone states and Washington, DC, and (3) earthquakes for six states in the U.S. West. The modeling required extensive data compilation, aggregation, processing, and analysis of the 18.1 million buildings constructed since 2000.

The study focused on the three dominant natural hazards in the United States: floods, hurricane wind, and earthquakes.

The analysis calculates the Average Annualized Losses Avoided (AALA) from adopting and enforcing building codes with hazard-resistant provisions. AALA is a risk-based metric of the aggregated savings for a community derived from comparing reduced I-Code damage to pre-I-Code construction damage. The CoreLogic national parcel dataset provided the study data backbone. See Table ES-1 for the data sources, data format, and methodology for the three hazards. The BCS Study team consisted of building performance specialists in flood, hurricane wind, and seismic hazards and specialists in building code history, economics, and big data analytics.

Figure ES-2 shows the input data processed by the number of new buildings constructed to I-Codes or similar standards between 2000 and 2016. The code adoption percentage varies substantially by year, as does the total number of new buildings constructed. However, the percentage of new buildings meeting I-Code or similar standards has remained relatively flat at about 70% since 2013, as has the total number of new buildings constructed (about 577,000 per year).

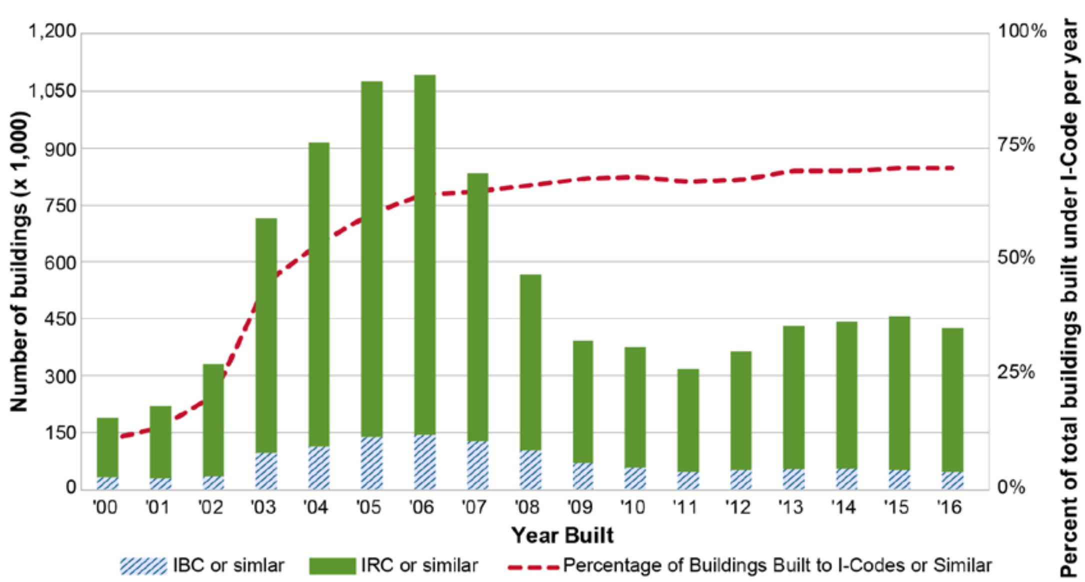

Figure ES-2: Buildings constructed to I-Codes or similar standards, 2000–2016

Table ES-1: Data Source, Data Format, and Methodology by Hazard

Data Source / Data Format / Methodology	Flood	Hurricane Wind	Seismic
Main national data sources, by hazard and by land use	CoreLogic parcel database, Microsoft footprint data, ASCE 7, ASCE 24, USACE, CRS, BCEGS	CoreLogic parcel database, Microsoft footprint data, ASCE 7, FBC, CRS, BCEGS	CoreLogic parcel database, Microsoft footprint data, USGS NSHM and on-line design ground motion tools, USGS Vs30 data, BCEGS
Supplemental hazard-specific data sources	Updated DDFs	Modified existing Hazus vulnerability curves and added extensive logic to make applicable building characteristics a function of building code and edition	Discussions with local Structural Engineers to support selection of MBTs, seismic hazard zone maps, near-source fault zone maps
Data format	Simulating Hazus User-Defined Facilities analysis (point data) in cloud database	Standalone Hazus Hurricane Wind Model (SHHWM) format (point data)	Advanced Engineering Building Module (AEBM) analysis (point data)
Hazard map condition nationwide	1 percent-annual-chance flood boundaries from NFHL and CoreLogic.	Published digital ASCE 7 maps and digitized prior versions	USGS on-line design ground motions and digitized maps from 1994/1997 UBC
Probabilistic hazard modeling basis	Used FEMA PELV Curves for flood profile for 5 events based on historic FEMA flood policy.	Full Hazus probabilistic event set (Monte Carlo simulation)	USGS 2014 Probabilistic 100-, 250-, 500-, 750-, 1000-, 1500-, 2000-, and 2500-year return period ground motion data from NSHM
Modeling procedure	Compare code based on freeboard provisions, assigning Hazus flood DDFs by structure and flood zone elevations	Assign hurricane wind damage related building characteristics where known based on parcel data for applicable building code.	Assign Design Levels for building based on strength required in each code edition. Use related Hazus damage functions per occupancy, MBT, and Design Level.
Pre-I-Code	NFIP minimum requirements	BOCA, CABO, SBC, and UBC (Hawaii)	1994 UBC

AEBM = Advanced Engineering Building Module
ASCE = American Society of Civil Engineers
BCEGS = Building Code Effectiveness Grading Schedule
BOCA = Building Officials and Code Administration
CABO = Council of American Building Officials
CRS = Community Rating System
DDF = Depth-Damage Function
FBC = Florida Building Code
FEMA = Federal Emergency Management Agency
ISO = Insurance Services Office
MBT = Model Building Type
NFHL = National Flood Hazard Layer
NFIP = National Flood Insurance Program
NSHM = National Seismic Hazard Maps
PELV = probability of elevation
QA = Quality Assurance
SBC = Standard Building Code
SBC = Standard Building Code
SFHA = Special Flood Hazard Area
SHHWM = Stand-alone Hazus Hurricane Wind Model
UBC = Uniform Building Code
USGS = U.S. Geological Survey
Vs30 = Shear wave velocity in the top 30 meters of soil
WBC = Wind Building Characteristic
WBDR = Wind-Borne Debris Region

National BCS Study Findings

Of the 18.1 million post-2000 buildings that were modeled in the BCS Study, about 51% (9.1 million) showed losses avoided resulting from the adoption of I-Codes.[1] The calculated AALA results (in 2020 dollars) were aggregated by occupancy to the county, state, and national levels for all three hazards.

Table ES-2 shows the AALA for I-Code (and similar code) modeled nationwide by hazard and a **total of $1.6 billion AALA.** These results confirm the BCS Study hypothesis both in national aggregate and in locally driven solutions.

Table ES-2: Average Annualized Losses Avoided by Hazard

Hazard	No. of Bldgs. Modeled[(1)]	AALA (x$1,000)
Flood	786,473	$483,602
Wind	9,200,267	$1,060,692
Seismic	2,441,923	$59,924
	Total AALA	**$1,604,218**

(1) The numbers of buildings that were modeled are not totaled because many were built to mitigate against more than one hazard.

Although flooding is the most common hazard, the flood hazard has the lowest nationwide exposed post-2000 building count of the three hazards, because most construction avoids the floodplain. Hurricane wind exposure covering half of post-2000 construction also has large areas within the high hazard Wind-Borne Debris Region, producing the dominant AALA achievement to date and future opportunity.

The six western seismic states, which account for 78.5% of the national AAL, show a low I-Code AALA compared to hurricane wind and flood because code seismic provisions have been incrementally reducing damage since the 1980s and the incremental changes post-2000 that can currently be modeled are focused primarily on hazard map changes. In short, the six seismic states have been accruing losses avoided for a longer period with a lower percentage of buildings producing AALA—mainly locations of significant map changes. Delving further into rankings of AALA by state, the top four states are Florida, Texas, California, and South Carolina, accounting for 80% of the total $1.6 billion AALA with only 60% of the number of new buildings being hazard-prone states.

The projected future I-Codes savings will compound to at least $3.2 billion per year AALA by 2040 for total cumulative losses avoided of $132 billion!

Projecting forward, based on an average of 577,000 new buildings per year, approximately 13.9 million buildings will be added to the U.S. inventory between 2016 and 2040. About 70% (approximately 9.7 million) will be built to I-Codes or similar codes. Based on the AALA results, the cumulative savings will be $132 billion. Further, if all buildings pre-I-Code were built to I-Code standards, the AALA would increase fivefold given they are currently

[1] Based on a total of 90 million parcels with buildings in the 2018 CoreLogic database, noting that 2017 and 2018 records were incomplete.

20% of the building inventory. A massive compounding effect emerges as a strong economic case for codes.

Findings can be used to inform policy, technical guidance, mitigation strategies, and advocacy to communities and stakeholders, such as:

- Use of AALA for quantifying all-hazards disaster risk reduction, which is a core criteria of Presidential Policy Directive 21, Critical Infrastructure Security and Resilience (2013).
- Show how increased adoption of up-to-date building codes to advance FEMA's mission to help people prepare for, mitigate, respond to, and recover from natural hazards.
- Use results to incentivize investment in mitigation, which is Objective 1.1 in FEMA's *2018–2022 Strategic Plan* (FEMA, n.d.) supporting the *National Mitigation Investment Strategy* (DHS, 2019).
- Use the BCS Study database as a baseline resource for other preparedness, mitigation, and research programs and policies. An example is the 2019 *Natural Hazard Mitigation Saves* study by the National Institute of Building Sciences, which correlates well with BCS and found that adopting the latest building codes saves $11 per $1 invested (NIBS, 2019).

Opportunities for code savings are abundant. Three top community priorities were identified by post-analytics of results:

- Counties with high hazard levels, high growth, and needs for code adoption yield large savings.
- The broad opportunity for I-Code savings is in housing everywhere. While average savings per building may be small, given housing constitutes about 80% of the building inventory, they aggregate to meaningful numbers in even small communities.
- A value proposition emerges for widespread urban housing needs of vulnerable families. Low income housing built to I-Codes reduces impacts to those least able to absorb them.

> *Currently, less than half of jurisdictions have hazard-resistant codes. The good news is that nearly 80% of construction is now in communities with I-Codes (or similar codes) in place.*

In conclusion, the promising community savings revealed in the BCS Study, especially their massive compounding effects into the future, will hopefully prompt increased state and local code adoption. Reduced damage and increased community resilience by adoption of modern I-Codes is shown to be achievable by joint effort and commitment by communities at all levels of government.

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Acronyms and Abbreviations

AAL	Average Annual Loss
AALA	Average Annual Losses Avoided
ADP	adopted
AEBM	Advanced Engineering Building Module
AELR	Annualized Earthquake Loss Ratio
ASCE	American Society of Civil Engineers
ASFPM	Association of State Floodplain Managers
ASTM	ASTM International
ATC	Applied Technology Council
AWS	Amazon Web Services
BCA	benefit-cost analysis
BCEGS	Building Code Effectiveness Grading Schedule
BCR	benefit cost ratio
BCS	Building Codes Save
BFE	base flood elevation
BI	Business Interruption
BOCA	Building Officials and Code Administration
BSB	Building Science Branch
BSMT	basement
BRV	building replacement value
BUR	built-up roof
C & I	contents and inventory
C&C	component and cladding
CABO	Council of American Building Officials
CALBO	California Building Officials
CAZ	Coastal A Zone
CFR	Code of Federal Regulations
CGS	California Geological Survey
CID	Community Identification
CL	Contents Loss
CM	Community Rating System Manual
COM	Hazus-specific commercial occupancies
COMM	commercial occupancies
COV	coefficient of variation
CRS	Community Rating System
CRV	contents replacement value
DDF	Depth-Damage Function
DFE	design flood elevation
DHS	Department of Homeland Security
FBC	*Florida Building Code*
FBCR	*Florida Building Code, Residential*
FDEM	Florida Department of Emergency Management
FEMA	Federal Emergency Management Agency
FFE	Finished Floor Elevation
FIA	(FEMA) Federal Insurance Administration
FIPS	Federal Information Processing Standard
FIRM	Flood Insurance Rate Map
FLASH	Federal Alliance for Safe Homes
FLP	full load path
FNSH	finish floor elevation
FRB	freeboard
GBS	General Building Stock
GBT	General Building Type
GIS	Geographic Information System
GUID	Globally Unique Identifier
Hazus	Hazards U.S.
HHWM	Hazus Hurricane Wind Model
HVAC	heating, ventilation and air conditioning
HVHZ	High-Velocity Hurricane Zone
IBC®	*International Building Code®*
ICC®	International Code Council®
I-Codes®	*International Codes®*
ID	Identification
IND	Industrial

IRC®	International Residential Code®
ISO	Insurance Services Office
JSON	JavaScript Object Notation
JV	Joint Venture
KNIME	Konstanz Information Miner
LA	losses avoided
LFE	lowest floor elevation
LMF	loss modification function
m/sec	meters per second
MBT	Model Building Type
MEP	mechanical, electrical, and plumbing
MH	multi-hazard (Hazus)
MMC	Multi-hazard Mitigation Council
mph	miles per hour
MRI	mean recurrence interval
MWFRS	Main Wind Force Resisting System
NEHRP	National Earthquake Hazards Reduction Program
NFHL	National Flood Hazard Layer
NFIP	National Flood Insurance Program
NFPA	National Fire Protection Association
NIBS	National Institute of Building Sciences
NIST	National Institute of Standards and Technology
NMSZ	New Madrid Seismic Zone
NOAA	National Oceanic and Atmospheric Administration
NR	not reported
NSHM	National Seismic Hazard Map
OMB	Office of Management and Budget
OSB	oriented strand board
PELV	probability of elevation
PGA	Peak ground acceleration
PFRA	Probabilistic Flood Risk Analysis
psf	pounds per square foot
PUC	Provisions Update Committee
QA	Quality Assurance
QC	Quality Control
RES	residential
SBC	*Standard Building Code*
SBCCI	Southern Building Code Congress International
SBT	Specific Building Type
S_{DS}	design spectral response acceleration parameter at short periods
SEAOC	Structural Engineers Association of California
SEI	Structural Engineering Institute
SF	square feet
SFBC	*South Florida Building Code*
SFH	single-family home
SFHA	Special Flood Hazard Area
SHHWM	Stand-alone Hazus Hurricane Wind Model
SPM	single-ply membrane
SQL	Structured Query Language
S_S	design response spectrum
SSTD	hurricane construction standard
SWR	secondary water resistance
TCPIA	Texas Catastrophe Property Insurance Association
TFMA	Texas Floodplain Management Association
TIGER	Topologically Integrated Geographic Encoding and Referencing
TRV	total (building plus contents) replacement value
UBC	*Uniform Building Code*
UDF	User-Defined Facility
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
UUID	Universally Unique Identifier
Vs30	shear wave velocity in the top 30 meters of soil
WA	Washington
WBC	Wind Building Characteristic
WBDR	Wind-Borne Debris Region
WBT	Wind Building Type
WERC	Wind Engineering Research Council
WFCM	Wood-Frame Construction Material

Glossary

Attribute. In a building database, an attribute is a structural or locational characteristic.

American Society of Civil Engineers (ASCE) standards. Standards developed by ASCE that "provide technical guidelines for promoting safety, reliability, productivity, and efficiency in civil engineering. Many ASCE standards are referenced by model building codes and adopted by state and local jurisdictions" (ASCE, 2020).

Average Annual Loss (AAL). Estimated long-term value of losses in any single year in a specified geographic area.

Average Annual Losses Avoided (AALA). Comparison of the baseline pre-I-Code AAL and the AAL for the building code in place at the time of construction.

BCS National Methodology. Six-step process to obtain and process available nationwide building parcel data and perform the Hazus loss avoided computations presented in this BCS Study report.

BCS Study. Abbreviation of the title of the study that is described in this report. The complete title is "Building Codes Save: A Nationwide Study – Losses Avoided as a Result of Adopting Hazard-Resistant Building Codes." Applying the BCS National Methodology, the BCS Study evaluated buildings constructed from the year 2000 through 2018 and compared the losses estimated for a building built to an assumed pre-I-Code to the losses estimated for the same building built to the actual I-Code (or similar code) in place at the time of construction, if adopted.

BCS Study area. The 50 U.S. states and Washington, DC.

Benefit-cost analysis. "Method that determines the future risk reduction benefits of a hazard mitigation project and compares those benefits to its costs" (FEMA, 2020a).

Building Code Effectiveness Grading Schedule (BCEGS). "The Building Code Effectiveness Grading Schedule (BCEGS®) assesses the building codes in effect in a particular community and how the community enforces its building codes, with special emphasis on mitigation of losses from natural hazards … The BCEGS program assigns each municipality a BCEGS grade of 1 (exemplary commitment to building code enforcement) to 10" (ISO Mitigation, 2020).

Building centroid. Single point representing the geometric center of a building footprint.

Building footprint. Polygon representing a building outline.

Building replacement value (BRV). Engineering-based building replacement value, determined for this study using the RSMeans-based Hazus 2018 Replacement Cost Model.

Building/structure. "Structure with 2 or more outside rigid walls and a fully secured roof, that is affixed to a permanent site" (FEMA, 2020f).

Census tract. Relatively permanent statistical subdivision of a county with an average of 4,000 inhabitants. Census tracts have a unique numeric code in each county (U.S. Census Bureau, n.d.a).

Code savings. Savings in terms of losses avoided for physical building damage, simplified as Average Annual Losses Avoided (AALA), as a result of the adoption of a building code.

Commercial building code. The BCS Study uses the term "commercial building code" to mean the building code for any building that is not used as a one- or two-family dwelling. In that context, the IBC is a "commercial building code" even though it covers other occupancies (e.g., industrial, education, some residential). In Hazus Occupancy Classes, commercial is one of seven general occupancy types (residential, commercial, industrial, agricultural, religious, government, and education), which is subject to IBC requirements. See Table 3-1 for Hazus Occupancy Class definitions and Appendix D, Table D-2, for Hazus Occupancy Class definitions, applicable codes (IRC/IBC), and IBC Flood Design Classes.

Contents replacement value (CRV). Replacement value of building contents (personal property not permanently attached to the structure), defined in Hazus as a fixed percentage of BRV by occupancy.

CoreLogic database. Tax assessor database with more than 100 data fields for individual parcels, including structure location, year built, and other structure categories required for a losses avoided analysis.

Damage curves (damage functions). Curves (functions) that relate hazard severity to structure damage for a particular structure type.

Dwelling. The International Residential Code (IRC) defines a dwelling as "any building that contains one or two dwelling units used, intended, or designed to be built, used, rented, leased, let or hired out to be occupied, or that are occupied for living purposes" (IRC, 2018). Hazus considers buildings containing more than one dwelling unit to be a dwelling (i.e., an apartment building is a multi-family dwelling).

Dwelling unit. "A single unit providing complete independent living facilities for one or more persons, including permanent provisions for living, sleeping, eating, cooking and sanitation" (IRC, 2018).

Emergent state. For the flood analysis, a state in which the available data sources indicate that freeboard requirements were adopted after 2000.

FEMA Community Rating System (CRS). "Program developed by FEMA to provide incentives for those communities in the [NFIP's] Regular Program that have gone beyond the minimum floodplain management requirements to develop extra measures to provide protection from flooding" (FEMA, 2020c).

FEMA Regions. FEMA consists of 10 Regions in the continental United States and territories. Regional offices work with state, local, tribal, and territorial governments. For the states and territories in each FEMA Region, see https://www.fema.gov/about/organization/regions.

Flood code. Provisions of building codes and community ordinances intended to ensure that structures can adequately resist flood forces.

Flood hazard study area. The Special Flood Hazard Area (SFHA) in all 50 U.S. states and Washington, DC. See "Special Flood Hazard Area."

Flood Insurance Rate Map (FIRM). "Official map of a community, on which … [FEMA] has delineated both the special hazard areas and the risk premium zones applicable to the community" (44 Code of Federal Regulations [CFR] § 59.1).

Flood modeling methodology. The process used in the BCS Study to analyze losses avoided when communities adopt a flood code.

Flood profile. Graph or table showing the flood elevations for various recurrence intervals for a single location or waterbody reach.

Flood Zone A (AE and A1-30). Areas subject to inundation by the 1-percent-annual-chance flood event determined by detailed methods. Used for riverine flooding and coastal flooding where modeled wave actions are less than 3 feet.

Flood Zone V (VE and V1-30). Areas subject to inundation by the 1-percent-annual-chance flood event with additional hazards due to storm-induced velocity wave action. Used for coastal flooding where modeled wave actions are 3 or more feet.

Freeboard. Additional height above the base flood elevation (BFE) that buildings are elevated to. Freeboard acts as a factor of safety to compensate for uncertainties in the determination of flood elevations and provides an increased level of flood protection.

GeoJSON. Open-source file format that converts spatial data into code so it can be used outside of a spatial program such as ArcGIS.

Hazard-resistant building code. Building code with provisions that provide a minimum level of building protection against natural hazards.

Hazard-resistant jurisdiction. Jurisdiction that uses the 2015 or later IBC and IRC edition without weakening provisions related to flood, hurricane wind, and seismic hazards.

Hazus. Nationally applicable standardized methodology that contains models for estimating potential losses from floods, hurricanes, earthquakes, and tsunamis. Hazus uses Geographic Information System (GIS) technology to estimate physical, economic, and social impacts of disasters. See https://msc.fema.gov/portal/resources/hazus for more information.

Hazus Advanced Engineering Building Module (AEBM) procedures. Hazus AEBM procedures are an extension of the more general methods of the Hazus Earthquake Model and provide building-specific loss estimation tools for use by experienced seismic engineers, Structural Engineers, or users with more detailed inventory data (FEMA, 2012b).

Hazus Design Level. Hazus Design Levels are used to distinguish between buildings that are designed to different seismic standards and expected to perform differently during an earthquake. In the original Hazus methodology, the differences are determined primarily on the basis of seismic zone location and design vintage. The original Design Levels are Pre-Code, Low Code, Moderate Code, and High Code. In the BCS Study, two Design Levels—Very High Code and Severe Code—were added, based on mapped seismic hazard contour data.

Hazus Hurricane Wind Model (HHWM). Hazus methodology used for estimating potential losses from hurricane winds.

Hazus Model Building Type (MBT). Structural types reflecting the building's earthquake lateral-force resisting system (see Table 6-1). Derived from FEMA-178 (FEMA, 1992b) with the addition of building height subclasses and mobile homes.

Hazus Occupancy Classes. Classifications of building use or occupancy as used in Hazus. The 33 classes (see Table 3-1) are grouped into the following seven general occupancy types: residential, commercial, industrial, agricultural, religious, government, and education.

Hazus Replacement Cost Model. Model based on industry-standard cost estimation methods published by RSMeans (RSMeans, 2020). The model was most recently updated in 2018.

Hurricane wind hazard study area. The 22 states included in the Hazus Hurricane Wind Model (Texas, Louisiana, Mississippi, Alabama, Florida, Georgia, South Carolina, North Carolina, West Virginia, Virginia, Maryland, Delaware, Pennsylvania, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, Maine, and Hawaii) and Washington, DC.

I-Code. See "International Codes."

Innovator state. For the flood analysis, a state in which the available data sources indicate that freeboard requirements have been in place since at least 2000.

International Codes (I-Codes). "Developed by the International Code Council, a family of coordinated, modern building safety codes that help ensure the engineering of safe, sustainable, affordable and resilient structures" (ICC, 2020).

Jurisdiction. The limits or territory within which authority may be exercised, such as by a county, town, or city.

Legacy code. A building code that predates and influenced the first published set of International Codes (I-Codes). The legacy codes are Council of American Building Officials (CABO) *One-and Two-Family Dwelling Code*, Building Officials and Code Administrators International (BOCA) *National Building Code*, Southern Building Code Congress International (SBCCI) *Standard Building Code* (SBC), and the International Conference of Building Officials *Uniform Building Code* (UBC). The CABO *One-and Two-Family Dwelling Code* is referred to in the BCS Study as "CABO," and the BOCA *National Building Code* is referred to in the study as "BOCA."

Life cycle cost analysis. Economic analysis method that is used to estimate or determine the entire cost of a building over its useful life.

Limited state. For the flood analysis, a state in which the available data sources indicated that freeboard requirements had been adopted only at the community level.

Loss cost. Average annual loss per $1,000 of building replacement value.

Losses avoided (LA). Cost savings from reduced damage.

Lowest floor elevation (LFE). Elevation "of the lowest floor of the lowest enclosed area (including basement). An unfinished or flood resistant enclosure, usable solely for parking of vehicles, building access or storage in an area other than a basement area is not considered a building's lowest floor; Provided, that such enclosure is not built so as to render the structure in violation of the applicable non-elevation design requirements of [44 CFR] § 60.3" (44 CFR § 59.1).

Mean recurrence interval (MRI). Estimated average time between events of a certain magnitude; also referred to as return period. A higher MRI represents a more severe event.

Model building codes. Nationally developed building codes used as the basis of a state or local jurisdiction's building code.

Modern building codes. FEMA defines modern building codes as the two most recent editions of the I-Codes (i.e., the 2015 and 2018 editions) for policy or grant approval purposes to incentivize using progressive improvements to hazard provisions. However, the BCS Study modeling of all post-2000 structures focused on comparing the larger contrast of pre-I-Codes and the many modern provisions that were introduced in the I-Codes in 2000.

National Flood Hazard Layer (NFHL). Geospatial database with current, effective flood hazard data. The NFHL is based on effective flood maps (i.e., FIRMs) and Letters of Map Change (FEMA, 2020f).

Natural disaster. Event in which a natural hazard causes significant harm to human life, property, or society.

Natural hazard. Naturally occurring weather event with the potential to harm human life or property. Natural hazards are divided into atmospheric (tropical cyclones, thunderstorms and lightning, tornados, windstorms, hailstorms, snow avalanches, severe winter storms, and extreme summer weather), geologic (landslides, land subsidence, and expansive soils), hydrologic (floods, storm surges, coastal erosion, and droughts), seismic (earthquakes and tsunamis), and other (wildfires and volcanic eruptions) (FEMA, 1997).

Negative losses avoided. Losses for the pre-I-Code condition are less than the losses for the I-Code (or similar code) condition. The I-Code (or similar code) yielded additional costs compared to the pre-I-Code condition.

New Madrid Seismic Zone (NMSZ) states. Eight states surrounding the New Madrid Seismic Zone: Alabama, Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee.

NFIP floodplain. Floodplain mapped by the NFIP. See “Special Flood Hazard Area.”

No losses avoided. Losses for the pre-I-Code condition that are equal to the losses for the I-Code or similar code condition (i.e., the I-Code or similar code yielded no cost savings compared to the pre-I-Code condition).

Non-residential building. Any building that is not assigned a residential building occupancy.

Normalized loss ratio. Average Annual Loss (AAL) as a fraction of the building inventory replacement value (i.e., dollar loss per million dollars of building value exposed).

Parcel. Plot of land that may contain one building (e.g., single-family dwelling) or more than one building (e.g., apartment complex).

Parcel centroid. A single point representing the geometric center of a parcel.

Probability of Elevation (PELV) curves. FEMA PELV Curves represent different flood profiles based on a logarithmic best fit line for event probability versus flood elevation. Each PELV Curve is based on a specific elevation difference between the 10-year (10 percent-annual-chance-event) and the 100-year (1-percent-annual-chance-event) flood elevations.

Positive losses avoided. Losses for the pre-I-Code condition exceed the losses for the I-Code or similar code condition (i.e., the I-Code or similar code yielded cost savings compared to the pre-I-Code condition).

Post-2000 building/structure. Building/structure built in the year 2000 or later.

Pre-I-Code. Code that is assumed to have been in place prior to the year 2000 (when the I-Codes were first published). For the flood hazard, the pre-I-Code condition is elevation of the lowest floor to the BFE based on NFIP minimum requirements. For the hurricane wind hazard, the pre-I-Code codes are BOCA, CABO, SBC, and UBC (Hawaii). For the seismic hazard, the pre-I-Code code is the 1994 UBC.

Residential building code. The BCS Study uses the term “residential building code” to mean the building code for one- and two-family dwellings (i.e., subject to IRC requirements). In the I-Codes, the IBC requirements apply to buildings that are residential but outside the scope of the IRC (e.g., apartment buildings, hotels). In Hazus Occupancy Classes, a one-family dwelling is denoted as RES1, and a two-family dwelling (a.k.a. duplex) is denoted as RES3A. RES1 and RES 3A are subject to IRC standards. Residential buildings with three or more units (denoted as RES3B, …, RES3F, RES4, RES5, or RES6 in Hazus) must be designed in accordance with the applicable commercial building code (e.g., IBC). Mobile homes (a.k.a. manufactured housing) are subject to U.S. Department of Housing and Urban Development design standards, which are separate from the building codes considered in the BCS Study.

Resilience. “The ability to withstand and recover rapidly from deliberate attacks, accidents, natural disasters, as well as unconventional stresses, shocks and threats to our economy and democratic system” (DHS, 2020).

Return on investment. Ratio comparing the net benefits of an action to its costs, calculated over a specific period of time.

Seismic code provisions. Code provisions that are intended to ensure that structures can adequately resist seismic forces during earthquakes. Seismic code provisions represent the best available guidance on how structures should be designed and constructed to limit seismic risk (FEMA, 2016).

Seismic hazard study area. The six western states with the highest seismicity: Alaska, California, Hawaii, Oregon, Utah, and Washington.

Similar to I-Codes. Building codes that predate the first I-Codes but are deemed similar codes because they contain similar requirements (e.g., SFBC, 1997 UBC). Additionally, post-2000 floodplain management regulations that contain freeboard requirements are modeled similarly to I-Codes with respect to freeboard requirements.

Special Flood Hazard Area (SFHA). “Land in the flood plain within a community subject to a 1 percent or greater chance of flooding in any given year. The area may be designated as Zone A on the Flood Hazard Boundary Map. After detailed ratemaking has been completed in preparation for publication of the Flood Insurance Rate Map, Zone A usually is refined into Zones A, AO, AH, A1-30, AE, A99, AR, AR/A1-30, AR/AE, AR/AO, AR/AH, AR/A, VO, or V1-30, VE, or V. For purposes of these regulations, the term ‘special flood hazard area’ is synonymous in meaning with the phrase ‘area of special flood hazard’” (44 CFR § 59.1).

Topologically Integrated Geographic Encoding and Referencing (TIGER) shapefiles. U.S. Census Bureau geographic product; extracts of selected geographic and cartographic information from the U.S. Census Bureau’s Master Address File/TIGER database (U.S. Census Bureau, 2019).

Total (building plus contents) replacement value (TRV). Cost to replace a building and its contents.

Total losses avoided. See ”Average Annual Losses Avoided.”

Wind-Borne Debris Region (WBDR). According to FEMA (2010), "ASCE 7-05 defines the windborne debris region as areas within 1 mile of the coastal mean highwater line where the basic wind speed is equal to or greater than 110 mph (and in Hawaii) and … areas where the basic wind speed is equal to or greater than 120 mph (130 mph and 140 mph in ASCE 7-10, respectively)."

Wind code provisions. Provisions of building codes intended to ensure that structures can adequately resist wind forces.

CHAPTER 1

Introduction

In response to the increasing cost of natural disasters and associated damage to buildings and community losses, FEMA has been working in partnership with local and state governments for decades to reduce losses from natural disasters by producing risk based hazard maps and by supporting improvements in the development and adoption of building codes to make communities more hazard resistant. Building codes have improved in a continual progression over the past few decades in response to observed building performance during natural hazards, changes in construction methods, and research and testing.

Natural Disaster Snapshot of the US

- Since 1980, the United States has sustained over $1.6 trillion in losses due to natural disasters, and the cost of natural disasters is increasing because of (1) increased severity and frequency of hazards and (2) population growth in hazard-prone areas (NOAA, 2019; NOAA, 2020).
- Flooding is the most common natural hazard—90% of natural disasters are floods, and flood risk exists in every county in the nation.
- Currently, only about half of the jurisdictions at risk of one or more hazards have hazard-resistant codes, with residential buildings accounting for over 80% of disaster damages. The good news is that nearly 80% of construction is now in communities with I-Codes (or similar codes) in place.

Buildings that are designed and constructed to modern building codes[1] withstand the effects of natural hazard events, including flooding, high winds, and earthquakes, better than buildings that are not (ICC, 2020a.). A 2019 study by the National Institute of Building Sciences found that adopting the latest building codes saves $11 per $1 invested (NIBS, 2019). The NIBS study also demonstrates how strengthened building codes for risk mitigation result in financial and economic benefits, which are expected to accrue over the life of buildings designed and constructed according to modern building codes. These benefits arise as avoided losses or savings.

The development and subsequent adoption of a single set of building codes with hazard-resistant provisions that are applicable at on a national scale began with the launch of the 2000 editions of the International Code Council's (ICC's) *International Building Code*® (IBC®), *International Residential Code*® (IRC®), and other ICC codes, collectively referred to as the International

[1] FEMA defines "modern building codes" as the two most recent editions of the I-Codes (2015 and 2018 editions).

Codes or (I-Codes). Other hazard-resistant building codes that are nationally applicable have also been developed, such as NFPA 5000 (NFPA, 2018).

Aside from ongoing code development, the magnitude of recent hazard events and the escalating cost of natural disasters together revealed a compelling need to quantify the value of building codes in reducing damage from natural disasters nationwide.

The study objective is to determine by analysis the losses avoided (cost savings from reduced physical damage) from adopting the I-Codes or similar building codes for the dominant natural hazards across the United States: flooding, hurricane winds, and earthquakes. The title of the study is "Building Codes Save" (BCS) because adopting the I-Codes or similar building codes results in significant savings that are intuitive but had not been measured.

What makes the BCS Study unique and challenging is the massive amount of local data that had to be collected, modified, and analyzed to generate a nationwide picture. Buildings constructed from 2000 through 2018 were evaluated using available records of the building parcels, mapped hazard exposure, and building code histories nationwide, notwithstanding data limitations.

The objective of the study was is to produce an estimate of the losses avoided (cost savings from reduced physical damage) resulting from the use of I-Codes and similar codes from flooding, hurricane wind, and earthquakes while recognizing the uncertainty in hazard exposure and building vulnerability. Hence, the full complete title of the study is, "Building Codes Save: A Nationwide Study – Losses Avoided as a Result of Adopting Hazard-Resistant Building Codes."

1.1 Goals of the Building Code Saves Study

The goals of the BCS Study are to:

- Demonstrate the monetary value of adopting I-Codes nationwide by quantifying the losses avoided (benefit) to commercial, industrial, and residential structures in flood-, hurricane wind-, and earthquake-prone areas. This was accomplished by modeling the performance of current hazard-resistant building codes (i.e., I-Codes in place at the time of construction) and comparing results to the performance of older building codes. Note, this detailed cost savings evaluation of I-Codes does not supplant the primary objective of building codes: to provide life-safety protection.
- Quantify the effect of I-Codes in lowering disaster risk for new construction in the Special Flood Hazard Area (SFHA), hurricane wind zones, and high seismic risk areas by comparing modeled results between hazards and with various exposure profiles across the nation.

> **Special Flood Hazard Area**
>
> Land area subject to flooding by the 1-percent-annual-chance flood is labeled the Special Flood Hazard Area (SFHA) on Flood Insurance Rate Maps (FIRMs). The SFHA is the area where National Flood Insurance Program (NFIP) floodplain management regulations must be enforced and where the mandatory purchase of flood insurance applies to federally backed mortgages.

- Present an all-hazards summary of findings that quantifies the calculated losses avoided. Use the data to determine opportunities under the current I-Codes for risk reduction, future code improvements to reduce risk, and collaboration opportunities with other Federal Emergency Management Agency (FEMA) risk reduction programs.
- Use the results to incentivize communities that have not adopted I-Codes to do so and thereby increase resilience in their communities and across the nation.
- Support an outreach and communication strategy to engage public officials and stakeholders to continue to support FEMA's strategic mission of reducing loss of life and property damage following natural hazard events.

1.2 Background on International Codes

The International Codes (I-Codes) are a family of 15 model building codes[2] that were developed and are maintained by ICC. The I-Codes cover all aspects of construction and include hazard-resistant provisions for flood, hurricane wind, seismic, and other hazards. The purpose of the I-Codes is to establish minimum requirements to protect life safety and reduce property damage. I-Codes are intended for states and local jurisdictions to use as the model basis for their building codes. For the codes to be effective, states and local jurisdictions must adopt the model codes and in doing so, they often need to amend the model codes to address local needs and interests (ICC, 2020b).

The I-Codes used in the BCS Study are:

- *International Residential Code* (IRC): Applies to one- and two-family dwellings and townhouses of not more than three stories in height and is primarily a prescriptive code (i.e., procedural).
- *International Building Code* (IBC): Applies primarily to buildings and structures other than one- and two-family dwellings within the scope of the IRC, although the IBC may be used to design dwellings. The IBC uses prescriptive and performance provisions when procedures can vary to meet a goal.

[2] Model building codes are building codes that are developed and maintained by standards organizations and used as the basis of state and local building codes.

While not evaluated as part of the BCS Study, the remaining 13 I-Codes are fully compatible with the IBC and IRC, and most contain hazard provisions.

Purpose of I-Codes

From 2018 IBC, Section 101.3: **"**Intent. The purpose of this code is to establish the minimum requirements to safeguard the public health, safety and general welfare through structural strength, means of egress facilities, stability, sanitation, adequate light and ventilation, energy conservation, and safety to life and property from fire and other hazards attributed to the built environment and to provide safety to firefighters and emergency responders during emergency operations" (ICC, 2018a).

IRC Section 101.3 is similar but also includes affordability as a primary intent (ICC, 2018b).

1.2.1 Code Development Process

The ICC updates the I-Codes every 3 years through a government consensus process—anyone can propose code changes, which are then voted on by officials and other employees of governmental departments or agencies that administer, formulate, and implement or enforce building codes or other rules and regulations related to public health, safety, and welfare.

Since the inception of the I-Codes in the year 2000, FEMA and its partners have contributed to and supported improved development of hundreds of hazard-resistant provisions of the I-Codes across the code versions released to date, and their reference standards. This is done by proposing and successfully advocating proposed code changes, based on lessons learned from FEMA post-disaster assessments use to develop improvements to best practices and guidance. It is an ongoing process.

1.2.2 Code Adoption

Although federal agencies may contribute to the I-Codes through the consensus process, the federal government does not develop or enforce building codes. Because of the U.S. Constitution's delineation of states' responsibilities and rights, state governments are responsible for determining how building codes and standards are adopted and enforced, if at all. States manage building code adoption in a variety of ways. Many states adopt building codes at the state level and mandate enforcement at the local level. Currently, most of the states adopt the I-Codes as their state codes, though many do not require or enforce building codes at the local level, allowing local jurisdictions to manage their own adoption practices.

Hazard Resistance in the Latest I-Codes

While the I-Codes have included hazard-resistant provisions since the first edition in 2000, hazard-resistant provisions are improved and expanded upon with each code edition and FEMA considers the two latest published editions of the I-Codes to be "modern." FEMA considers a community to be hazard resistant if it adopts a modern code without weakening the hazard-resistant provisions. Adopting the latest code editions increases safety and reduces financial losses, supporting more rapid recovery after disasters.

Also, some states specify which codes are allowed to be adopted so the result is widely varying local adoption practices.[3]

To address local concerns, states and communities typically make amendments and modifications, including higher and lower standards, additions, and deletions. When building codes are mandated by the state, jurisdictions may or may not be allowed to further amend the codes, and some states prohibit local jurisdictions from weakening the codes (e.g., removing the flood freeboard requirement, lowering design wind speeds). States (and jurisdictions, if allowed) set the schedule for how frequently they update or amend their codes. Each state has its own name for its state code; for example, California adopts the California Building Code, and Oregon adopts the Oregon Structural Specialty Code for commercial buildings and the Oregon Residential Specialty Code for residential construction. Chapters 4, 5, and 6 of this report include tables showing code adoption status and histories for states that are subject to the various hazards.

1.2.3 History

The I-Codes were first published in 2000, bringing together the following legacy codes with regional limitations:

- Council of American Building Officials (CABO), *One- and Two-Family Dwelling Code*
- Building Officials and Code Administrators International (BOCA), *National Building Code*
- Southern Building Code Congress International (SBCCI), *Standard Building Code* (SBC)
- International Conference of Building Officials, *Uniform Building Code* (UBC)

Figure 1-1 highlights the major changes to I-Codes that are relevant to the BCS Study and the hazards it covers (flood, hurricane wind, and seismic). BCS Study modeling of all post-2000 structures applied the appropriate version of the I-Codes for each structure based upon year built and adopted version in place at that time. This as-built code version is the basis from comparison to pre-I-Codes. Chapters 4, 5, and 6 of this report describe the relevant history of the I-Codes in more detail by hazard.

[3] For latest ICC records of I-Code adoption by state, see https://www.iccsafe.org/advocacy/.

1997	2000	2003	2006	2009	2012	2015	2018
General	First edition of I-Codes End of legacy codes (NBC, SBC, UBC) First year of BCS study period	New edition of I-Codes	New edition of I-Codes	New edition of I-Codes	New edition of I-Codes	New edition of I-Codes Last code edition used in BCS study period due to adoption lag	Last year of BCS study period New edition of I-Codes
Flood	IBC/ASCE 24-98: limited freeboard requirements[1]		IBC/ASCE 24-05: new freeboard requirements for most structure categories[1]	IRC: New freeboard requirements in Coastal High Hazard Areas[2]		IRC: 1 foot of freeboard required in all flood hazard areas IBC/ASCE 24-14: new freeboard requirements[1]	
Hurricane Wind	IBC and IRC reference ASCE 7-98 wind maps		IBC requires opening protection in the Wind-Borne Debris Region		IBC and IRC reference ASCE 7-10 updated wind maps		I-Codes reference ASCE 7-16, with updated wind maps and updated roof design loads
Seismic The seismic provisions of the 1997 UBC and 2000 IBC produce seismic designs of similar strength	Change in major earthquake design ground motion				Change in major earthquake design ground motion		

(1) ASCE 24 requirements for freeboard modeled indirectly when available state and local freeboard data indicated freeboard for these structures. See Appendix D, Table D-1, for more details.

(2) IRC freeboard requirements in Coastal High Hazard Areas modeled indirectly when available state and local freeboard data indicated freeboard for these structures

Figure 1-1: Timeline of I-Code changes modeled in the BCS Study

1.2.4 Cost Impact of Building Codes

Building to code may contribute to higher initial building costs, but the added cost of hazard-resistant provisions is small. *Natural Hazard Mitigation Saves: 2019 Report* (NIBS, 2019) estimates the following marginal increases to construction costs for applying hazard-resistant provisions of the 2018 I-Codes:

> **Potential Follow-On Analysis**
>
> Analyzing the cost impact of building codes is not within the scope of the BCS Study but is a consideration for potential follow-on analysis (see Section 7.2).

- Flood: 1.2 to 1.7% increase for adding 1 foot of freeboard
- Hurricane wind: 1% increase for building envelope and roof elements, compared to 1990 requirements

- Earthquake: 0.7% increase to comply with stiffness and strength requirements, compared to 1988 requirements

To put these cost into perspective, note that the sales price of a building is nearly double the construction cost, making the percentage impact of financing the codes about half of these values when considering land value and developments (e.g., road, utility, grading, fencing, landscaping). These small percentages are arguably affordable for mortgages compared to other home features commonly included in homes. Hazard-resistant provisions are not the only contributors to increased construction costs. When a change is proposed to the I-Codes (see Section 1.2.1), proponents are required to include a statement regarding how the change will impact the cost of construction. Cost impact is considered with the benefits of the proposal.

Other costs include those to states and communities associated with adoption and enforcement. Adopting codes on a regular cycle incurs costs for staffing and public meetings, as well as purchasing new code books for building departments and training for code officials. Enforcement activities such as plan review and inspection are typically funded, at least in part, by permit fees. Permit fees may be based on the value of the proposed building; therefore, permit fees may increase as well. These are largely the kinds of costs associated with well managed government agencies to reduce errors, efficiently administer services, and thereby add value to the public.

1.3 Summary of Phases 1, 2, and 3

The methodology and results of the BCS Study culminate from findings and lessons learned during the three preliminary phases of the study: Phase 1, a pilot study; Phase 2, a FEMA Region IV demonstration study; and Phase 3, development of a National Methodology (see Figure 1-2).

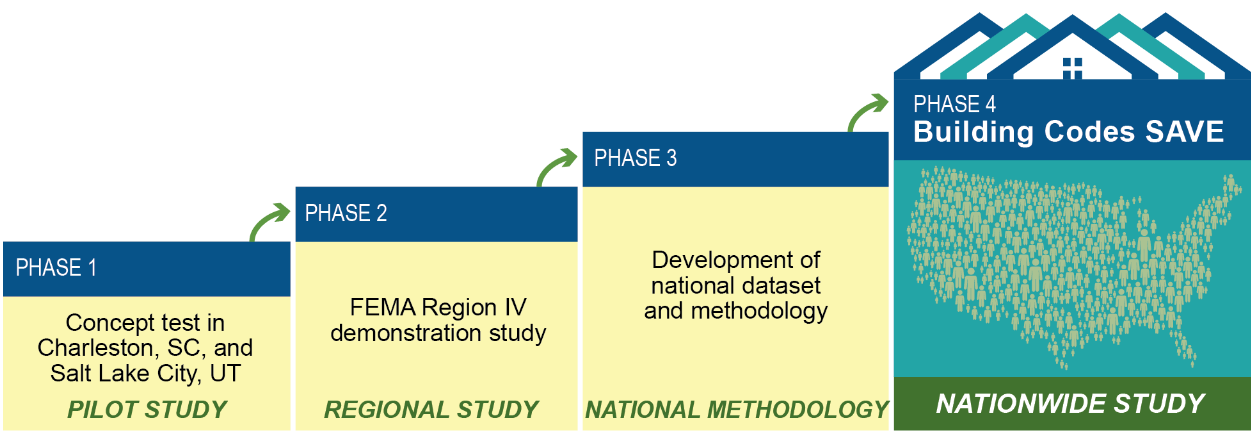


Figure 1-2: The four phases of FEMA's Building Codes Save Study

1.3.1 Phase 1: Pilot Study

The Phase 1 Pilot Study was completed in 2012 (FEMA, 2012f). It evaluated losses avoided resulting from the adoption of I-Codes (or similar building codes) in Charleston County, South Carolina, for flood and wind events; and in Salt Lake County, Utah, for earthquake events.

1.3.2 Phase 2: FEMA Region IV Demonstration Study

The Phase 2 FEMA Region IV Demonstration Study, completed in 2014 (FEMA, unpublished), evaluated the losses avoided resulting from the adoption of I-Codes (or similar codes) for buildings in the SFHA in FEMA Region IV, modeling flood, hurricane wind, and earthquake events. Phase 2 built on the work in Phase 1 by using efficiencies of using a first generation commercial parcel database from CoreLogic for the 8 states comprising Region IV, rather than obtaining records directly from each county in those states. This demonstrated that millions of parcel records could be filtered, processed, and used to create Hazards U.S. (Hazus) modeling input and computational runs.

1.3.3 Phase 3: Development of National Methodology

Phase 3 incorporated the findings of the Phase 2 Region IV Demonstration Study to develop a national methodology. The BSC nationwide study is built on this methodology. Key characteristics of Phase 3 are:

- **Building parcel assessor data:** The CoreLogic assessor database required significant filtering to identify and format the post-2000 construction parcels. A standardized data filtering process developed in Phase 3 greatly increased the efficiency of Hazus input file preparation.
- **Hazards data:** Existing nationwide digital wind and seismic hazard data layers made it easy to assign design hazard exposure to each parcel in Phase 2. However, more effort was required to verify flood zone boundaries for parcels exposed to flood hazard. An open-source, updated National Flood Hazard Layer (NFHL) was developed for use in Phase 4 (BCS Study).
- **Damage functions:** Expert opinion and analysis provided a basis for mapping and assigning existing Hazus damage functions to pre-I-Code and I-Code (or similar) building types.
- **Codes:** Modeling the losses avoided resulting from the adoption of building codes was greatly simplified and more reliable in states that had adopted and mandated enforcement of building codes statewide. States that had not mandated statewide code adoption required a significantly greater effort to model and had a reduced amount of data. As a result, the accuracy in states without mandates was less than for states that had statewide adoption of building codes.

1.4 Organization of the Report

The report is organized as follows:

- Executive Summary – Summary of the key points of the report
- Chapter 1: Introduction – Background on the BCS Study; goals of the study; background on the I-Codes; summary of Phases 1, 2, and 3; and report organization
- Chapter 2: Overview of the National Methodology – Methods applied in Phase 4 of the study (BCS Study)
- Chapter 3: Data Collection and Filtering – Overview of the data collection, filtering, and processing methods to develop the data used for modeling all three hazards
- Chapters 4, 5, and 6 – Hazard-specific modeling methodologies, including unique input formatting, processing, and Hazus computations performed for flood, hurricane wind, and earthquake hazards
- Chapter 7: Findings – Findings from the BCS Study
- Chapter 8: Advancing Community Benefits Nationwide – Economic considerations and outreach to engage stakeholders and maximize risk reduction
- Chapter 9: Conclusions and Actions for Resilience – Conclusions and next steps
- Chapter 10: References
- Chapter 11: Acknowledgements

Additional material is provided in appendices, as follows:

- Appendix A: CoreLogic Data Summary and AALA Results
- Appendix B: Building Code Data
- Appendix C: Data Processing Methodology and Quality Control
- Appendix D: Flood Hazard Methodology Details
- Appendix E: Wind Hazard Methodology Details
- Appendix F: Seismic Hazard Methodology Details

CHAPTER 2

Overview of the National Methodology

Chapter 2 presents an overview of the National Methodology used to obtain and process available nationwide building parcel data and perform the loss avoided computations with Hazus modeling. The methodology generally followed developed in Phase 3. Some required adaptations of the data filtering and processing methods are presented in Chapter 3 of this report. Hazard-specific elements of the methodology are presented in Chapter 4 (flood hazard), Chapter 5 (hurricane wind hazard), and Chapter 6 (seismic hazard) of this report.

Attributes of 18.1 million post-2000 buildings from across the 50 states and Washington, DC, were obtained from the CoreLogic national parcel database and other sources. They were filtered and processed including assignment of building code version and hazards exposure for analysis using the Hazus method and software (v4.2 Service Pack 3). The “granular” sub-county aggregation of individual parcel results was to allow local level insight to hazard exposure, building inventory patterns, and code adoption patterns influencing the determination of losses avoided and other benefits. Subject matter experts and professional design engineers and data specialists conducted the evaluations and data analysis for each hazard. The method included post-analytics of results to obtain insights into the demographics and priority opportunities for reduced losses in flood, hurricane wind, and seismic hazards across the nation.

The numerical modeling of buildings under hazard loadings prioritized the code factors more feasible to model, such as flood freeboard, window shutters, and ties to complete the load path. Figure 2-1 shows basic hazard-resistant provisions of the I-Codes modeled in the BCS Study compared to the pre-I-Codes.

2.1 Applied National Methodology

The BCS Study evaluated buildings constructed from the year 2000 through 2018 and compared the losses estimated for a building built to an assumed pre-I-Code code to the losses estimated for the same building built to the actual I-Code (or similar code) in place at the time of construction.

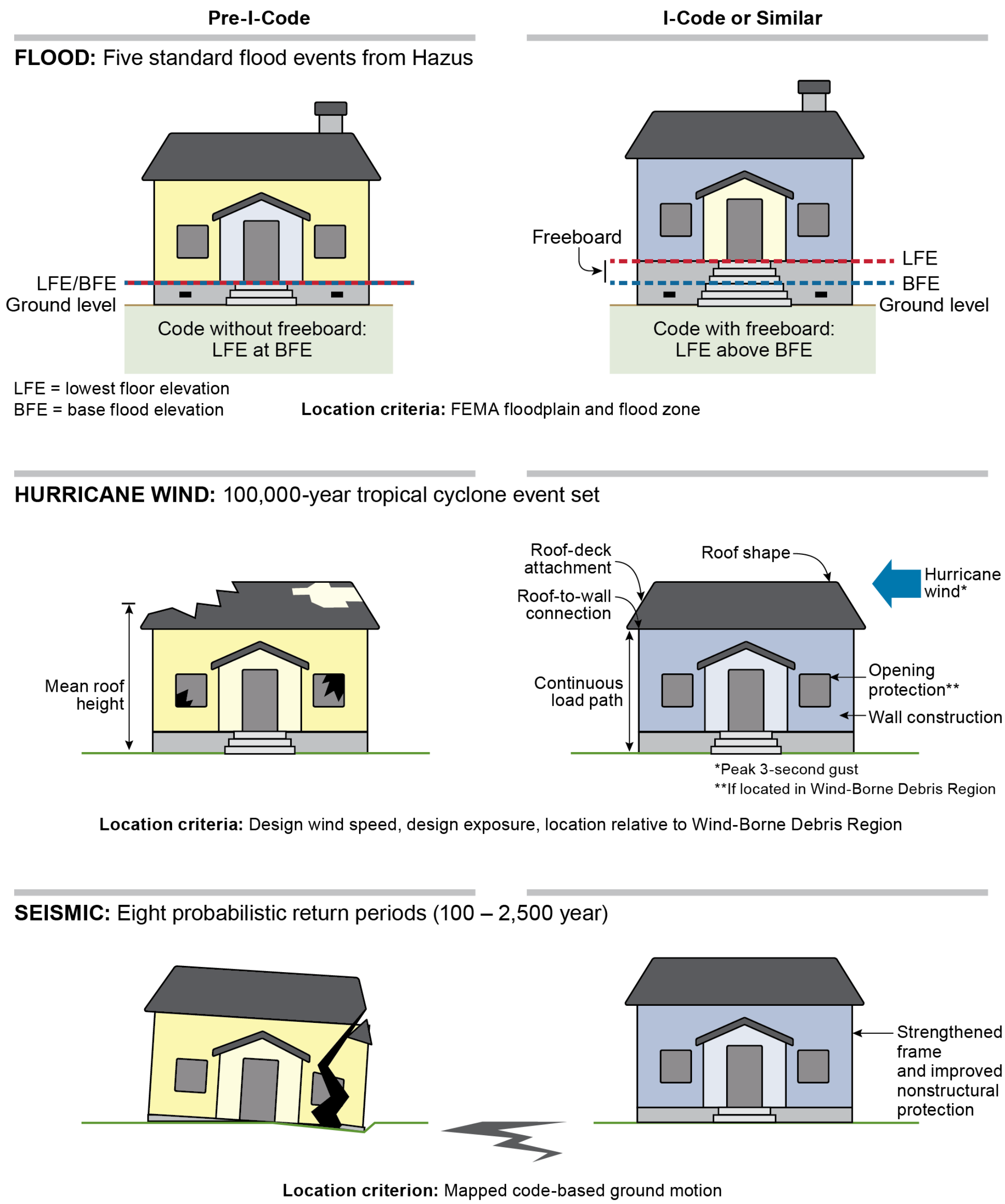


Figure 2-1: Basic modeled provisions of the I-Codes compared to the pre-I-Codes

Pre-I-Codes and I-Codes or similar codes are defined as follows:

- "Pre-I-Code," which varies for each hazard, refers to the code that was in place prior to the year 2000 when the I-Codes were first published:
  - For the flood hazard, the pre-I-Code condition[4] is elevation of the lowest floor to the base flood elevation (BFE) based on NFIP minimum requirements.
  - For the hurricane wind hazard, the pre-I-Code codes are BOCA, CABO, SBC, and UBC (Hawaii) (see Section 5.1.1).
  - For the seismic hazard, the pre-I-Code code is the 1994 UBC (see Section 6.1.1).
- "I-Code or similar code" refers to the actual I-Code or similar code in place at the time of construction, if adopted. The I-Code or similar code varies by year a building was built and its location. Some codes that predate the first I-Codes are deemed similar codes because they contain similar requirements, such as the 1997 UBC. The similar codes are described further in Chapters 5 and 6.

The metric for measuring I-Code savings with pre-I-Code savings is Average Annual Losses Avoided (AALA):

- The BCS Study applied a losses avoided calculation framework to AAL. Losses avoided methods (which can be considered savings or benefits from prevented damage prevented) are used by FEMA for in assessing hazard mitigation projects. Losses avoided are determined by comparing damages to a building that used a hazard-resistant building code to damages that would likely have been caused by the same hazard events prior to that code).
- The application of building code losses avoided calculations using metrics of AAL produces an AALA, which allows normalization of benefits across hazards and for relative effectiveness, as a percentage of AAL.
- Therefore, AALA is readily relatable to insurers, economists, municipal finance, and risk planners in a benefits framework. With some familiarization of ALA as a metric, the public can understand the BCS Study findings as annual savings from reduced disaster damage to buildings over a period of years from adopting I Codes.

Average Annual Losses Avoided Methods

Average Annual Losses Avoided (AALA) are a statistical measure of the benefits due to adoption of building codes with flood, hurricane wind, and earthquake provisions.

Average Annual Loss (AAL) is the expected loss per year for a range of hazard events of differing probabilities. AAL can be used as a comparative metric between disaster events and hazard types, risks, and spans of time. It is a key metric in insurance premium models and can be included in life cycle cost analysis and return on investment calculations.

[4] Because lowest floor elevation requirements are found in floodplain management regulations as well as in building codes, the term "pre-I-Code condition" is used.

For these reasons, the BCS Study as a nationwide study on loss prevention used AALA as its principal result.

The National Methodology consists of six steps:

Step 1: Perform data collection and filtering to identify relevant data

- Collect data: hazard maps, building code history, and building data
- Determine predominant hazard-resistant building code provisions for each hazard by the locations that are modeled, focusing on actual measurable benefits
- Profile the history of building code adoption by states and communities

Step 2: Adapt and assign damage curves

Damage curves (also known as damage functions) relate hazard severity to structure damage for a particular structure type. Based on the building inventory, determine whether existing damage curves in Hazus would represent building damage behavior under the pre-I-Code condition or under the I-Code (or similar) condition for a given code year. If neither condition applies, adapt or create damage curves to represent the damage for a hazard.

Assign existing, adapted, and created damage curves to buildings for pre-I-Code and I-Code (or similar) conditions for flood, hurricane wind, and seismic hazards.

Step 3: Input data into analysis tool (Hazus)

Format building data and input data into Hazus for a Level 2 analysis, along with adopted building codes and relevant hazard maps in place at the time of construction.

Hazus Level 1 and 2 Analyses

Level 1 Analysis – Default Data Analysis: Default data are used to characterize the study area to develop initial rough loss estimates.

Level 2 Analysis – User-Supplied Data Analysis: Improved hazard and building inventory data are incorporated to yield more accurately modeled estimates of damage and loss.

Step 4: Compute and analyze damage and economic losses and losses avoided

Compute economic losses avoided by comparing the losses estimated for buildings designed under the I-Codes to the same buildings designed under previous codes.

Step 5: Evaluate losses avoided findings

Normalize results to produce AALA values in a standardized format to allow comparison across hazard, occupancy type, and location.

Step 6: Perform quality assurance of results

Conduct an independent evaluation by technical data experts not involved in the data processing or modeling to assess the accuracy of the process and results.

2.2 Why Hazus?

FEMA's Hazus is a standardized software and modeling methodology widely used decision-support software for estimating potential losses from floods, hurricane winds, and earthquakes, being the dominant natural hazard losses in the United States. Hazus uses GIS technology to estimate spatially the physical, economic, and social impacts of hazard events, allowing large-scale computations of parcels, communities, counties and states. The results in turn can be further aggregated up to the national level as with BCS. The Hazus GIS methodology also provides proven engineering-based computations that are compatible with widely used design methods.

Hazus was chosen to quantify avoided losses in the BCS Study because of its key advantages – 1) A consistent methodology across the three hazards. 2) Flexibility to accommodate damage function modifications (needed to simulate effects of building code provisions that reduce building damage). 3) Communities nationwide are familiar with Hazus for its primary function as a well-documented, practical, and nationally consistent emergency planning tool and data backbone that is widely used by federal, state, and local officials.

To provide consistent data inputs and computations for a meaningful comparison of code performance by structure to produce losses avoided, BCS used the following software and data:

- Hazus 4.2 Service Pack 3, May 2019 release
- Hazus modeling methodologies for advanced processes not contained in the current Hazus software
- 2018 Hazus building replacement value (BRV) data
- 2010 census data for parcel aggregation
- ArcGIS 10.5.1 as the geospatial platform for compiling parcel data, Hazus output, and other data

2.3 Hazard Design Level Events

The following building code-based probabilistic Design Level events (a specified suite of event return periods) were used to develop probability exceedance curves and generate modeled losses avoided in terms of AALA :

- For flood, the 1-percent-annual-chance (100-year) event (the basis for the regulatory FEMA BFEs and flood boundaries) was used for the initial calculations and then extended to 10-, 4-, 2-, and 0.2-percent-annual chance (10-, 25-, 50-, and 500-year) events.
- For hurricane winds, a 100,000-year event set (a Monte Carlo Simulation of differing probability events up to 100,000 years) was used to generate calculated AALA. The Hazus

hurricane event set is consistent with the return periods used to generate wind speed hazard maps in ASCE 7-16 for hurricane-prone states.

- For earthquakes, data were derived from the U.S. Geological Survey (USGS) 2014 National Seismic Hazard Maps (Petersen et al., 2014) for eight return periods (100-, 250-, 500-, 750-, 1000-, 1500-, 2000-, and 2500-year).

2.4 Simulations for Building Code Provisions

Building code provision modeling in Hazus requires organizing the data to Hazus run format and protocols. The default conditions for the pre-I-Code baseline and for adaptation to simulate I-Code provisions are described in the following subsections, followed by a discussion of modeling time lag adjustments imposed by the data.

2.4.1 Hazus Runs or Simulations for Pre-I-Code Provisions

Hazus model computations of pre-I-Code provisions were completed using baseline assumptions that correspond to the building characteristics reflective of the building code provisions in place prior to the state's adoption of the I-Codes or similar codes. Expected economic damages corresponding to the pre-I-Code case were compiled from the results for each hazard.

2.4.2 Hazus Runs or Simulations with I-Code or Similar Provisions

Hazus model computations of I-Code (or similar) provisions were performed with modified building characteristics reflect the building code provisions of the adopted I-Codes (or similar codes) in place at the time of construction. Detailed discussion is provided in Chapters 4 through 6. The basic concept is as follows:

- For flood, the freeboard condition scenario is modeled by adjusting the first-floor elevation.
- For hurricane wind modeling, the default building stock distribution assumptions in Hazus is modified on a building-by-building basis to reflect known architectural attributes (e.g., construction type, number of stories, roof shape) when available and presumed structural attributes (e.g., roof-to-wall connection, roof-deck attachment, windborne debris protection) based on a building's location/jurisdiction, year of construction, and code adoption history.
- For earthquake modeling, the incremental benefit of building code adoption is modeled primarily by adjusting the Design Level (seismic shaking intensity) categorization of buildings based on the expected building strength evaluated under each code edition. The building strength is according the mapped shaking intensity.

2.4.3 One-Year Code Adoption Lag

In the methodology for all three hazards, all code adoption dates from sources such as the ICC are adjusted forward by 1 year to approximate the year the building code was fully implemented. For example, if the 2012 IRC edition was adopted in 2014, the effective year is 2015.

The primary reason for the lag is uncertainty related to the available data sources and the actual code adoption date relative to the construction permit date. The year-built data in the CoreLogic database have considerable uncertainty because the year-built date could represent an initial building permit at the design stage, the final inspection of the completed building when the certificate of occupancy is issued, or something in between.

Likewise, the code adoption dates listed in alternative sources such as the Insurance Services Office (ISO) Building Code Effectiveness Grading Schedule (BCEGS) data could represent any time during a year. Very few buildings are completed in less than 6 months, so there is uncertainty with assigned dates. For example, near code adoption dates, builders, designers, and owners frequently make extra effort to get permit applications approved before new codes go into effect to avoid possible delays and/or increased costs due to required design changes.

2.5 Losses Avoided Computations

The losses that were evaluated in the BCS Study were damage to property such as buildings and contents. Economic losses related to building damage (e.g., lost rent, relocation costs, lost wages) are not available in the Hazus flood User-Defined Facility (UDF) module, and computations for multiple-event recurrence intervals were unreliable for losses avoided; therefore, economic losses are described along with other secondary impacts and community benefits in Chapter 7.

The losses avoided (or direct economic benefits) associated with I-Code and similar building code provisions were computed for each hazard scenario as the difference between the results of the Hazus runs with and without I-Code and similar building code provisions. Chapter 3 expands upon the data procession portion of the methodology. The processes used to evaluate the findings and perform quality assurance of the results are described by hazard in Chapters 4 through 6.

CHAPTER 3

Data Collection and Filtering

The BCS Study is fundamentally a large data model combining multiple data sources into one nationwide building-level database processed by the Hazus model. The Hazus model required assigning attributes (e.g., number of stories, building code, year built) to the building or buildings on a parcel. A parcel is a plot of land that may contain one building (e.g., single-family dwelling) or more than one building (e.g., an apartment complex). Primary data inputs were grouped into four bins:

- **Attributes of buildings** (see Section 3.2.1) to model in Hazus, representing a total of 18.1 million buildings.
- **Hazard information** (see Section 3.2.2) including exposure maps (I-Codes, ASCE/SEI 7, USGS, *Florida Building Code* [FBC]), damage functions (Hazus and the U.S. Army Corps of Engineers), and other data.
- **Hazus Replacement Cost Model** (see Section 3.2.3) national average cost per square foot assigned by Hazus Occupancy Class, with county-level location factors applied to reflect local cost conditions and custom handling of single-family dwellings to apply average census block-level costs per square foot determined from current Hazus default inventory data.

Within the four bins of data were data processing platforms and techniques that were used to filter and clean data and fill data gaps in order for the model to be able to calculate losses avoided for the highest possible number of post-2000 parcels. Secondary data were used when the primary data were insufficient and included building footprints obtained from Microsoft and local, hazard-specific parameters, such as foundation and garage information.

The type of available data varied by structure age. Data for structures designed after the adoption of the I-Codes, including code edition and hazard information, were often readily available and in digital format. I-Codes are updated every 3 years, with seven I-Code editions in the 18-year building history (2000, 2003, 2006, 2009, 2012, 2015, and 2018). Each I-Code edition was evaluated individually because new editions may contain significant changes. Building code and associated hazard information for structures designed to pre-I-Code standards was not as readily available and required inquiries, adjustments, modifications, or digitization.

Sections 3.1 and 3.2 describe the data that were used in the study, and Section 3.3 describes the data quality processes that were used.

3.1 Building Code Adoption Data

Building code adoption data for state and local jurisdictions were collected nationwide. The sources of data were as follows:

- ICC website
- Insurance Services Office (ISO) State Fact Sheets
- ISO BCEGS data
- FEMA Community Rating Service (CRS) building code ratings and freeboard criteria
- FEMA Building Code Adoption Tracking System for conveying BCEGS data
- Discussions with building officials and design professionals
- Internet research

ISO and FEMA CRS data are updated at different intervals, and there are differences in geographic coverage in each type of data. Building code parameters were assigned to parcels in the national dataset based on location.

3.1.1 State-Level Code Adoption

The states that have adopted building codes were identified by reviewing ISO State Fact Sheets (ISO, 2017; 2018b; 2018c), BCEGS (ISO, 2019), FEMA's Building Code Adoption Tracking System, and by searching the internet. See Section 1.2.3 for information on how states and also communities adopt building codes.

Figure 3-1 and Figure 3-2 show state-level adoption of the IBC and the IRC, respectively.

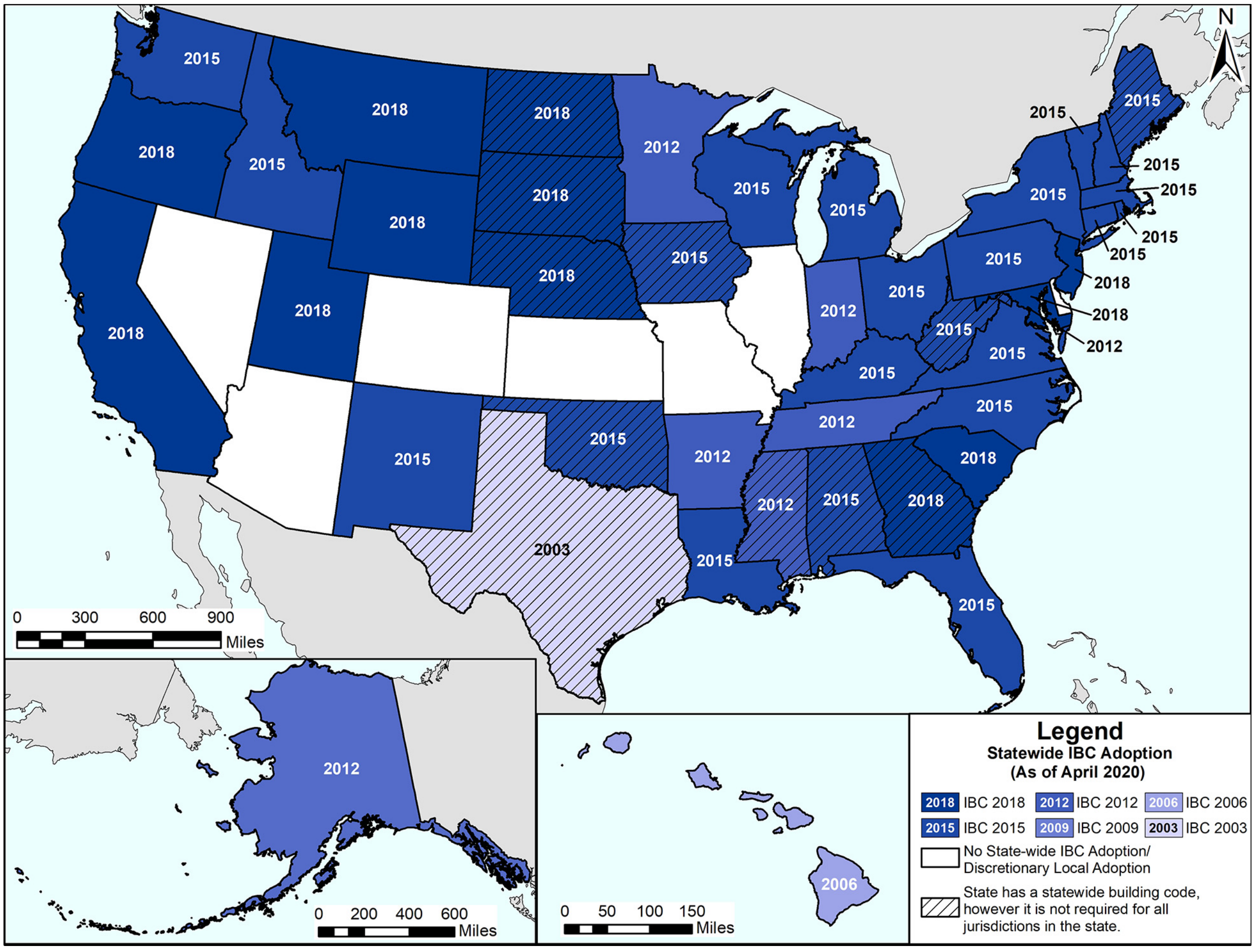


Figure 3-1: State-level adoption of the IBC as of April 2020

3.1.2 Building Code Effectiveness Grading Schedule Data

The ISO develops data that include building code adoption and enforcement and programs that support mitigation of losses from natural hazards, including floods, damaging winds, hurricanes, and earthquakes. The data are put into a rating system called the BCEGS, which ISO developed based on interviews with building departments. BCEGS covers approximately 22,000 communities nationwide. BCEGS does not include communities in every state because some states have their own rating systems (e.g., Wisconsin, Washington, Louisiana, Hawaii).

BCEGS data are currently considered the best available indicator of how a community enforces its building codes. The data are used for insurance rating and underwriting purposes. BCEGS assigns each community a rating of 1 (highest commitment to mitigation) to 10 (lowest) based on its commitment to adopting and enforcing building codes. BCEGS data are updated every 5 years on a rotating cycle and are reported to FEMA quarterly.

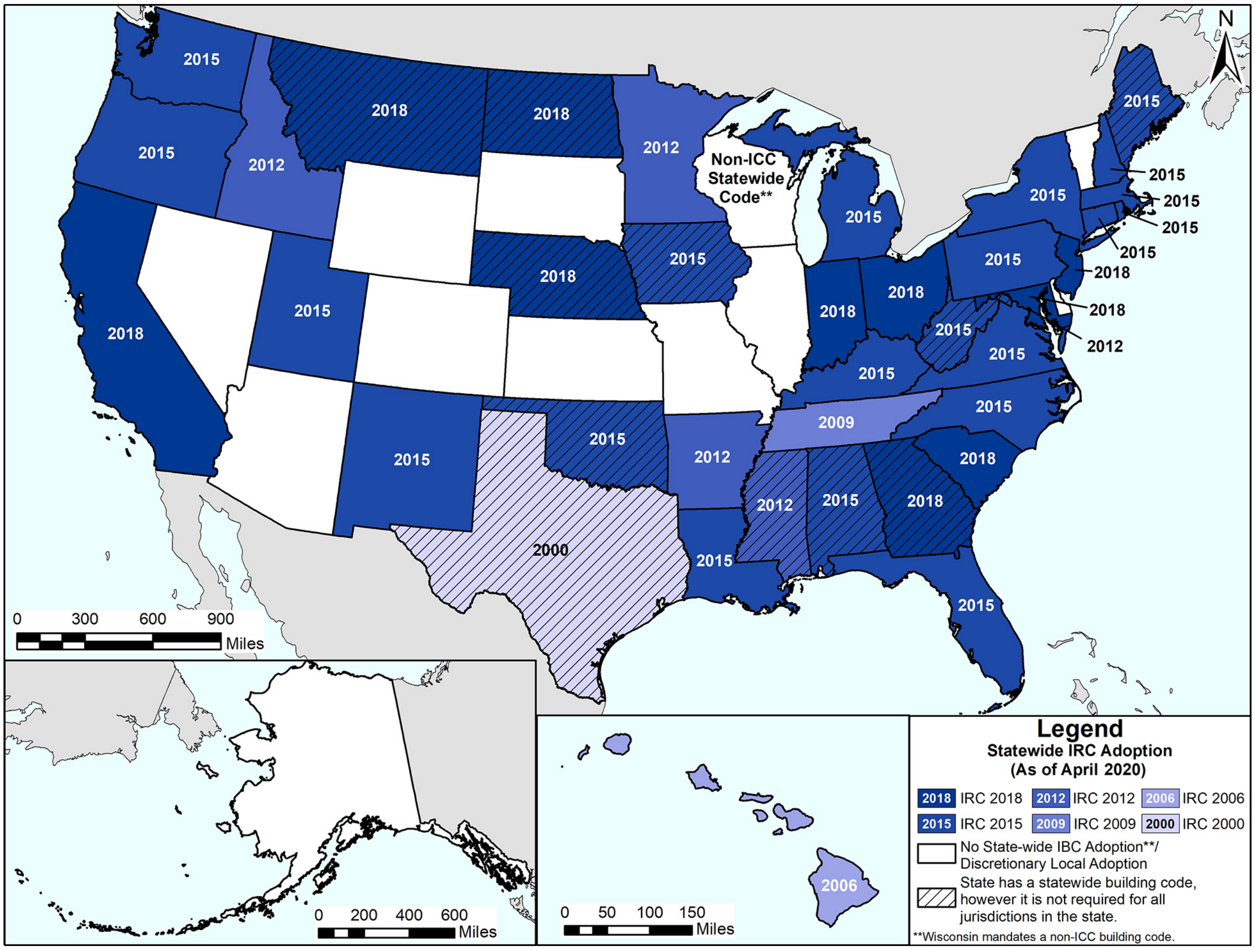


Figure 3-2: State-level adoption of the IRC as of April 2020

BCEGS data were used in the BCS Study to assign building code adoption and enforcement information in communities that are in states that have not adopted codes statewide and to refine data in communities that are in states that have adopted codes statewide.

FEMA uses BCEGS data in its Building Code Adoption Tracking System to monitor the adoption of hazard-resistant codes but enhances the data through research and analysis. Recognizing that hazard-resistant provisions in I-Codes are improved with each new edition, FEMA periodically updates the definition of hazard resistant. Generally, a jurisdiction is considered hazard resistant if it uses either of the two most recent editions of the IBC and IRC without weakening provisions related to flood, hurricane wind, and seismic hazards. A jurisdiction is the limits or territory within which authority may be exercised, such as by a county, town, or city.

Building code enforcement varies by jurisdiction. As noted above, a jurisdiction is the limits or territory within which authority may be exercised, such as by a county, town, or city. The state and local governments adopt and/or enforce laws, codes, regulations, or ordinances for the geographic area within its authority, such as for building codes. Some states have rigorous enforcement programs that include required training for building code officials and required permit reviews, and some designate responsibility for code enforcement to local jurisdictions. Some states and other jurisdictions do not require enforcement.

Despite code enforcement and other uncertainties in modeling data and methods, the quality of the building stock was assumed to be reliable (i.e., to have been constructed with reasonable inspection and enforcement measures such that the default assumption is that buildings were constructed to meet code provisions).

The effects of the varying degrees of code enforcement have not been thoroughly investigated, resulting in substantial uncertainty about enforcement. However, the absence of community enforcement does not necessarily mean that builders and developers do not follow code provisions since developers carry liability insurance, and most jurisdictions require that design drawings for buildings constructed under the IBC are signed and sealed by a Professional Engineer who is licensed by the state. Some jurisdictions also require signed and sealed drawings for one- and two-family dwellings constructed under the IRC. On the other hand, strong enforcement programs in a community can rapidly become overtaxed during periods of high growth, and construction quality can suffer from a lack of enforcement oversight, insufficient skilled workforce, and competing, schedule-driven priorities. For example, a strong correlation between building damage and construction quality was identified after Hurricane Andrew in 1992 with a preponderance of damage in the areas that had experienced rapid growth (FEMA, 1992a).

BCEGS data can serve as an efficient and uniform basis for evaluating enforcement. BCEGS rating components provide a view of community resources, training, and local regulatory commitments and therefore provide a broad basis for assessing trends and likely conditions. Unfortunately, BCEGS enforcement-related data is not available for many of the jurisdictions modeled. While containing a score of enforcement quality, it was used in the BCS Study only broadly to categorize communities that scored well on enforcement. The data also provided a general sense of the reliability of the calculated losses avoided in the BCS Study and could also serve as a basis for an investigation of correlations between the BCS Study and other studies.

3.2 Parcel-Level Assessor Data

Section 3.2.1 describes the nationwide CoreLogic parcel-level assessor data that were obtained and how the data were used in the BCS Study. The extensiveness of the data, which consisted of more than 147 million parcel records and over 200 potential fields per parcel, required systematic filtering and formatting of the data (see Section 3.2.1). Section 3.2.1 also addresses the variability of CoreLogic data, which were derived from a wide variety of jurisdictional formats and practices, resulting in a need to test the reliability of the data and format the data for use in Hazus.

Section 3.2.2 describes the other sources of the parcel-level data that were used in the study. Section 3.2.3 describes the Hazus Replacement Cost Model, which was used in the study and provided an efficient and consistent basis for developing Hazus-compliant input data.

3.2.1 Acquisition, Filtering, and Formatting of CoreLogic Data

FEMA purchased nationwide CoreLogic parcel-level assessor data, the primary dataset that was used in the BCS Study. The dataset consisted of more than 147 million parcel records and required significant filtering to identify and format valid, post-2000 construction parcels.

Purchase of CoreLogic Dataset for a Nationwide Study

FEMA was able to obtain a nationwide parcel dataset from CoreLogic covering all 50 states. The dataset included:

- Information from the national assessor database
- Building permit data
- License for FEMA project-specific use
- Data on all buildings in multi-building parcels

Partial CoreLogic nationwide parcel data are available through Department of Homeland Security (DHS) Homeland Infrastructure Foundation-Level Data (HIFLD) at https://gii.dhs.gov/hifld/.

The filtering reduced the dataset from 147 million parcel records to 16.2 million parcel records. Because a parcel may contain more than one building, the parcels were de-aggregated into individual buildings, and all of the building information was included in the attribute data to better approximate the exact number of buildings and their locations using Microsoft Bing building footprint data. The 16.2 million parcels represented a total of approximately 18.1 million buildings. Figure 3-3 illustrates the parcel data filtering procedure to establish the model database. Figure 3-4 shows the post-2000 CoreLogic national data coverage by county. Figure 3-5 is a heat map of the post-2000 building density nationwide.

For this study, high-priority areas, such as (e.g., areas of with high-density populations density in regions that are prone to floods, hurricane winds, and earthquakes), were filtered to assess dominant trends, while areas with low-density growth populations and areas with low vulnerability to floods, hurricane winds, and earthquakes were filtered out.

After the building data were obtained, hazard-appropriate Hazus-compatible databases were created using the CoreLogic building data, combined with the Microsoft Bing building footprint data for post-2000 buildings. The CoreLogic data were filtered to ensure that the data were in the correct format for Hazus software. For hurricane wind modeling, data were aggregated by census block. The data were processed and filtered as follows:

Step 0. Process the data based on available spatial information (latitude, longitude, and community location).

Step 1. Remove vacant parcels and parcels with unknown land use.

Step 2. Remove parcels with buildings built before the year 2000.

Step 3. Remove parcels with buildings that have 0 square feet. Merge parcels that are stacked on top of each other (e.g., apartment buildings, condominiums).

Step 4. Remove parcels with less than 500 square feet of building area.

Step 5. Identify Microsoft Bing building footprints on parcels. Merge parcels on large footprints (footprints that include multiple neighboring parcels) into a single building unit (see Figure 3-3).

Step 6. Categorize the parcels into Hazus Occupancy Classes (see Table 3-1) using the number of footprints per parcel, number of units per parcel, and CoreLogic land use.

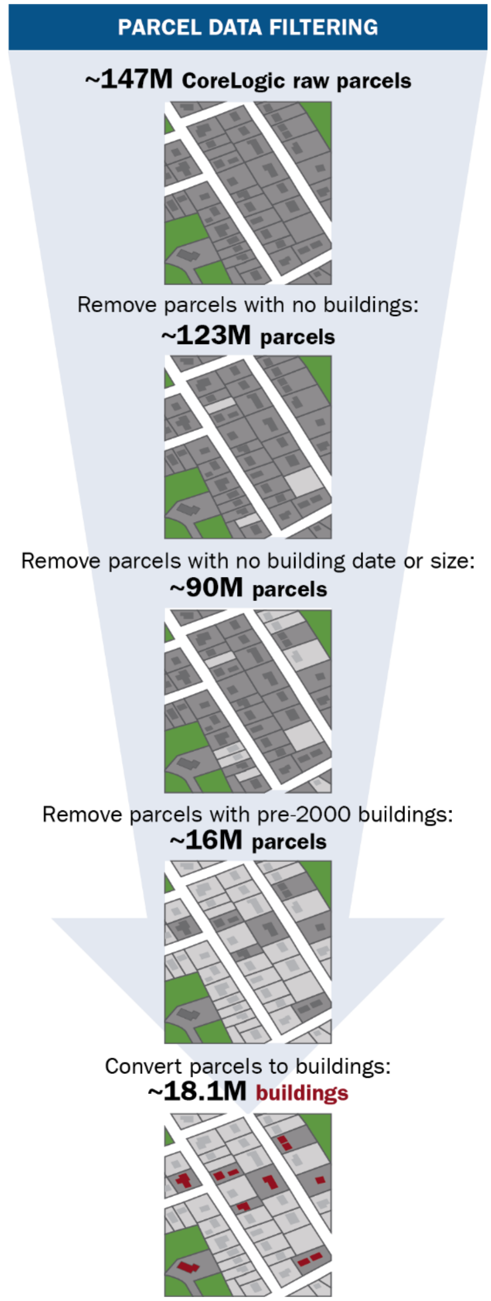


Figure 3-3: Parcel dataset filtering to build the database for the BCS Study

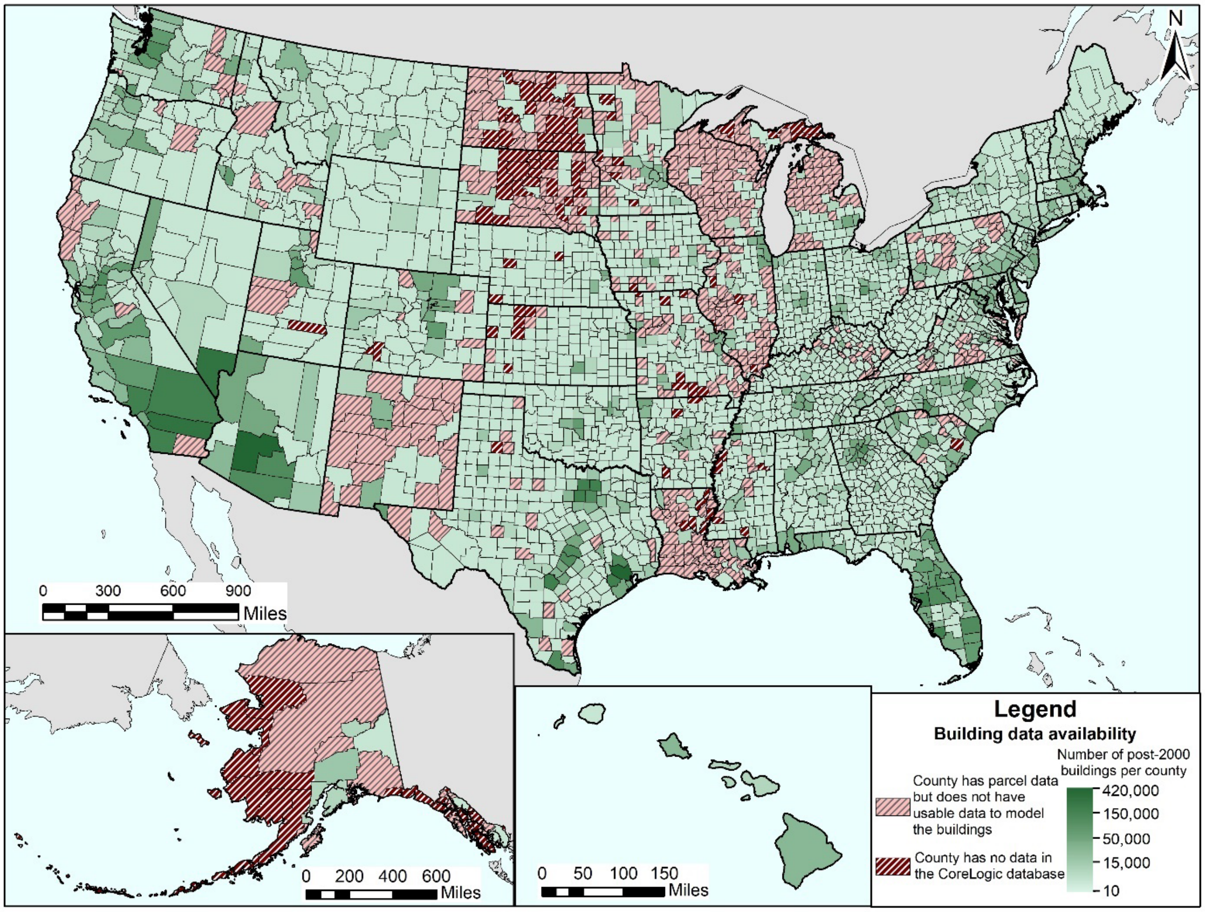


Figure 3-4: Post-2000 filtered CoreLogic building data availability per county

Step 7. The CoreLogic parcel data were then combined with Microsoft Bing building footprint centroid data in order to determine precise locations of the buildings in the parcels, census blocks, wind speed estimates, and flood zone locations. The total square footage per parcel was divided proportionately based on footprint size to the individual buildings (for multi-building parcels). Convert parcels with no building footprints into parcel centroids.

Step 8. Merge remaining stacked parcels, which were not previously identified because of nonsymmetrical geometries.

Step 9. Combine building centroids with location information (e.g., census block, census tract) and hazard-specific data (e.g., wind speed, flood zone).

Step 10. Remove counties with fewer than 10 building centroids.

See Appendix A for a summary of the processed and filtered CoreLogic parcel data, and Appendix C for a detailed discussion of the filtering and processing procedures.

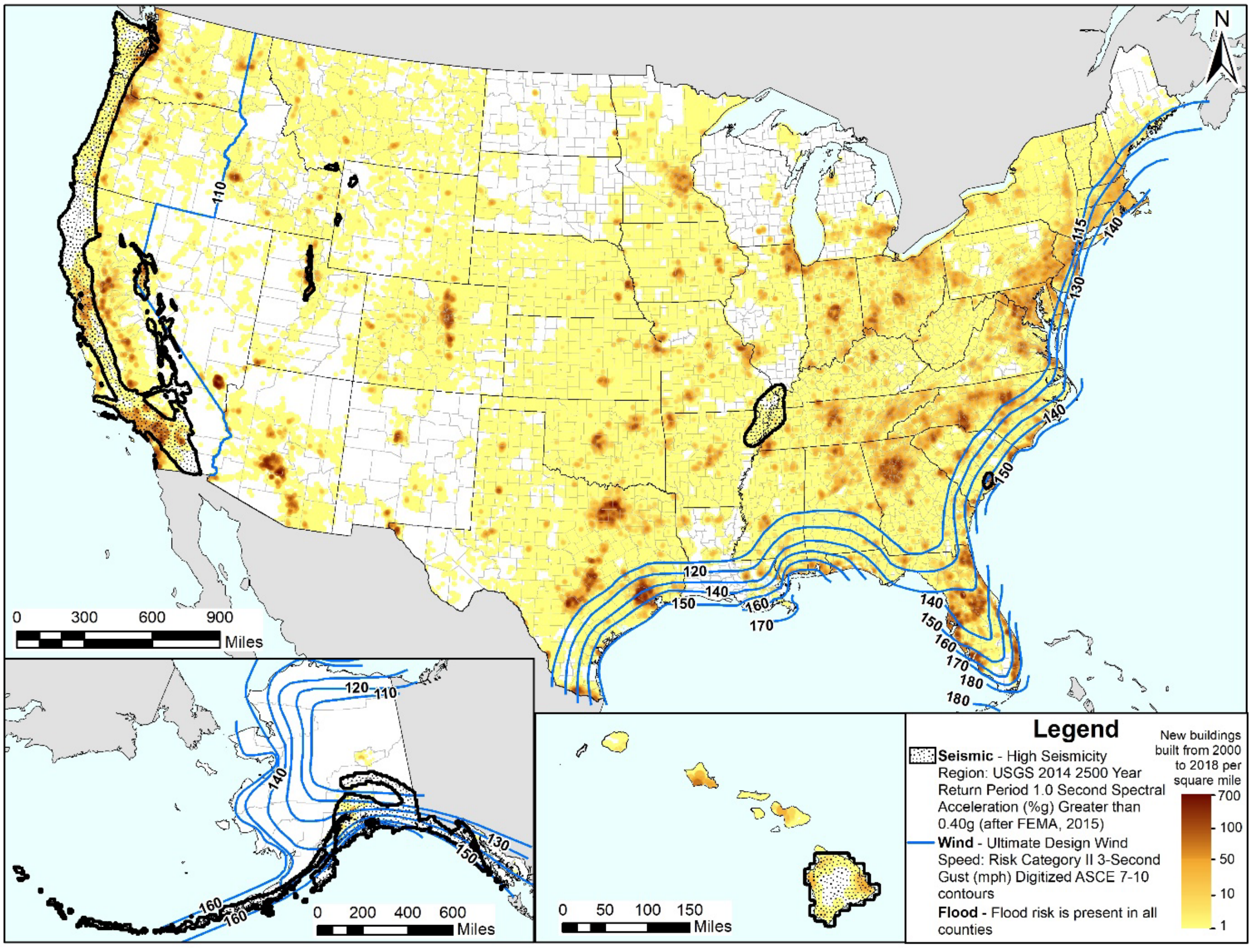


Figure 3-5: Post-2000 filtered CoreLogic building density

Table 3-1: Hazus Occupancy Class Definitions

Class	Class Description	Class	Class Description
RES1	Single Family Dwelling	COM7	Medical Office/Clinic
RES2	Mobile Home	COM8	Entertainment & Recreation
RES3A	Multi Family Dwelling – Duplex	COM9	Theaters
RES3B	Multi Family Dwelling – 3–4 Units	COM10	Parking
RES3C	Multi Family Dwelling – 5–9 Units	IND1	Heavy
RES3D	Multi Family Dwelling – 10–19 Units	IND2	Light
RES3E	Multi Family Dwelling – 20–49 Units	IND3	Food/Drugs/Chemicals
RES3F	Multi Family Dwelling – 50+ Units	IND4	Metals/Minerals Processing
RES4	Temporary Lodging	IND5	High Technology
RES5	Institutional Dormitory	IND6	Construction
RES6	Nursing Home	AGR1	Agriculture
COM1	Retail Trade	REL1	Church/Membership Organizations
COM2	Wholesale Trade	GOV1	General Services
COM3	Personal and Repair Services	GOV2	Emergency Response
COM4	Business/Professional/Technical Services	EDU1	Schools/Libraries
COM5	Depository Institutions (Banks)	EDU2	Colleges/Universities
COM6	Hospital		

3.2.2 Other Parcel Data Sources

In addition to the CoreLogic parcel-level data, which were obtained in early 2018 and were the backbone of the BCS Study data analysis, the following data were included:

- **Microsoft Bing building footprint data**: Used to determine precise locations of buildings in a parcel by spatially joining the parcels to the building footprints. Building footprints were also used to identify where building footprints spanned across multiple neighboring parcels, which were then combined into a single building point. Footprint data were obtained from Microsoft in late 2018.
- **Hazus census block and tract boundaries**: Used to populate the location of the building points in the county and state and provide location-specific estimated building and contents value calculation multipliers. The 2010 census block and tract boundaries were obtained from Hazus in 2019.
- **Topologically Integrated Geographic Encoding and Referencing (TIGER) county and state data**: During preliminary processing of CoreLogic data, TIGER county and state geographic information was used to tag all of the CoreLogic data with location information. The location information in the CoreLogic dataset was often incomplete or incorrect. The data were replaced when the census blocks were used to calculate county and state location later in the processing, but the TIGER data were useful for early location identification and for displaying counties and states on maps. County and state data were obtained from the U.S. Census Bureau in early 2019.

- **ISO BCEGS building code data**: Used to determine locally applicable building codes in jurisdictions where statewide codes are not mandated. BCEGS building code data were obtained in 2020.
- **CRS building code data:** Used to determine freeboard building requirements for locations nationwide. CRS building code data were obtained in 2020.
- **National Flood Hazard Layer (NFHL)**: Used to determine the flood zone location for each building footprint. NFHL data were obtained from FEMA in 2018.
- **National Flood Insurance Program (NFIP):** The NFIP provided details on the NFHL and supplemented the current NFHL with historical paper panels obtained from CoreLogic. The vintage of the NFIP panels was determined based on the date of the NFHL or CoreLogic flood hazard layer vintage.
- **CoreLogic flood hazard layer**: Used as a supplement to the NFHL when the NFHL was absent. CoreLogic flood hazard layer data are a digitized version of SFHA boundaries from historical paper NFIP panels. The data were obtained from CoreLogic in 2018 and are based on the latest known vintages of non-NFHL areas.
- **National Oceanic and Atmospheric Administration (NOAA) coastline information**: Used to identify buildings within 1 mile of the coast along the East and Gulf Coasts of the United States and Hawaii for wind hazard calculations. Coastline data were obtained from the NOAA website in late 2018.
- **ASCE/SEI 7 wind maps (**1993**,** 1998**,** and 2010 **editions)**: The ASCE wind maps were used to determine estimated peak gust wind speeds for the wind hazard calculations.
- **U.S. Geological Survey (USGS) probabilistic ground motion data provided in Hazus**:
  - USGS 2014 2,500-year spectral acceleration data at 1.0-second period (FEMA, 2012c; Petersen et al., 2014) were used to identify high seismicity regions following the approach in FEMA (2015a).
  - USGS 2014 National Seismic Hazard Map data for peak ground acceleration (PGA) and spectral acceleration at 0.3 second and 1.0 second for eight return periods (100-, 250-, 500-, 750-, 1,000-, 1,500-, 2,000-, and 2,500-year) (FEMA, 2012c; Petersen et al., 2014) were used to estimate Average Annual Losses (AALs).

3.2.3 Hazus Replacement Cost Model

The Hazus Replacement Cost Model (FEMA, 2012c) includes a national average cost per square foot for each Hazus Occupancy Class, along with county-specific location factors that account for differences between local and national average costs. The BCS Study used the Hazus Replacement Cost Model to estimate replacement costs for each analyzed building, with a specialized approach for single-family dwellings (Hazus Occupancy Class RES1), described further below. The cost basis for the Hazus Replacement Cost Model was updated to 2018 for this study. Hazus developers used the updated model to update the Hazus default databases, which are available to all users. Hazus contents replacement values (CRVs; FEMA, 2012c) are expressed as a percentage of the BRV; residential occupancies use 50%, commercial occupancies use from 50 to 150%, and industrial occupancies generally use 150%.

The Hazus RES1 (single-family dwelling) Replacement Cost Model is complex. It uses the ratio of census block, median household income to census region, median household income to determine local building Construction Classes (luxury, custom, average, or economy), which are used to estimate the replacement cost per square foot of the main structure. Costs for basements and garages are added using Hazus regional default distributions to determine the frequency and type of the basement and garage.

In the BCS Study, an approximate cost per square foot for RES1 construction was developed for each census block from the updated 2018 replacement cost data in the Hazus default inventory database. The 2018 replacement values were used to provide consistency with the Hazus replacement value methodology for all structures, even though new construction tends to have higher relative replacement values. Because the RES1 costs were based on the already localized costs, no additional modification was required. Building CRVs were estimated using the Hazus content value model (FEMA 2012c), which expresses CRVs as a percentage of BRV by occupancy.

Table 3-2 shows the total number of buildings in the processed post-2000 CoreLogic database, as well as square footage, BRV and CRV, by state, while Table 3-3 shows the national totals by Hazus Occupancy Class. As shown in Table 3-2 the national database includes more than 17 million post-2000 buildings, valued at more than $8.5 trillion. The states with the largest BRV are Texas (12% of the national total), California (11%) and Florida (9%). As can be seen in Table 3-3, most of the buildings (89%) are one- and two-family dwellings, whose design would be governed by the IRC (or similar code). These structures, however, represent 65% of the BRV, with other residential and commercial buildings, whose design would be governed by the IBC (or similar code) each representing 15% of the national BRV.

3.3 Data Quality

Evaluating the losses avoided for the entire nation required tens of millions of bits of parcel-related data that had to be organized, evaluated, supplemented, and carefully maintained to avoid corrupting or misinterpreting the data. The following sections describe the data quality-related issues in the BCS Study that were addressed, namely accuracy, gaps, data processing, quality control, and data validation.

Table 3-2: Summary of the National Database of Processed Post-2000 CoreLogic Building Data by State (2000 to 2018)

State	No. of Buildings	Total Square Footage (x1,000)	BRV ($M)[(1)]	CRV ($M)[(1)]
Alabama	374,443	921,747	$118,015	$74,938
Alaska	41,492	84,122	$16,082	$9,035
Arizona	751,206	2,177,983	$307,979	$193,468
Arkansas	222,661	408,895	$44,623	$22,529
California	1,388,971	4,975,455	$938,605	$563,920
Colorado	458,424	1,455,356	$217,438	$131,627
Connecticut	85,483	314,061	$63,044	$40,760
Delaware	77,264	175,179	$29,525	$15,005
Washington, DC	4,762	98,540	$16,319	$12,553
Florida	1,775,701	5,582,526	$740,875	$443,344
Georgia	923,382	2,697,118	$377,659	$221,798
Hawaii	54,402	109,288	$21,063	$12,089
Idaho	183,208	437,306	$61,541	$37,166
Illinois	261,798	825,642	$175,614	$102,416
Indiana	426,104	1,250,723	$193,040	$125,169
Iowa	195,838	509,843	$77,706	$50,885
Kansas	168,676	471,556	$76,780	$49,483
Kentucky	192,388	441,411	$57,865	$37,676
Louisiana	108,918	319,767	$40,530	$28,710
Maine	49,312	114,786	$16,287	$10,291
Maryland	259,637	1,092,246	$175,653	$104,428
Massachusetts	150,320	593,580	$116,657	$75,260
Michigan	158,291	513,884	$79,478	$45,478
Minnesota	293,862	938,343	$173,509	$108,056
Mississippi	250,100	550,735	$62,588	$40,086
Missouri	328,607	788,162	$126,195	$76,844
Montana	109,585	255,284	$32,526	$20,679
Nebraska	127,463	361,847	$54,624	$34,585
Nevada	353,102	1,073,614	$179,936	$103,447
New Hampshire	77,561	215,273	$34,526	$21,568
New Jersey	244,922	786,121	$172,067	$94,161
New Mexico	108,382	255,718	$33,025	$19,658
New York	322,046	1,193,626	$243,279	$137,635
North Carolina	970,226	2,736,371	$387,901	$231,369
North Dakota	25,853	79,083	$12,120	$7,970
Ohio	531,592	1,556,783	$244,829	$156,662
Oklahoma	331,732	786,751	$97,185	$64,030
Oregon	268,523	635,024	$97,441	$57,696
Pennsylvania	404,483	1,340,496	$224,129	$142,483

Table 3-2: Summary of the National Database of Processed Post-2000 CoreLogic Building Data by State (2000 to 2018) (cont.)

State	No. of Buildings	Total Square Footage (x1,000)	BRV ($M)(1)	CRV ($M)(1)
Rhode Island	20,743	62,826	$11,675	$7,598
South Carolina	429,580	1,098,611	$156,694	$89,474
South Dakota	40,665	112,568	$16,086	$10,525
Tennessee	577,340	1,485,118	$186,448	$118,083
Texas	2,539,003	7,551,484	$1,015,270	$641,097
Utah	256,631	698,958	$98,025	$56,034
Vermont	14,353	32,412	$4,821	$2,986
Virginia	480,340	1,663,815	$276,734	$162,266
Washington	553,027	1,669,816	$271,856	$169,814
West Virginia	98,870	190,990	$25,377	$13,617
Wisconsin	42,023	1,671,620	$290,991	$155,788
Wyoming	58,827	147,225	$19,235	$11,998
Total	**18,172,122**	**55,509,687**	**8,511,473**	**5,164,236**

(1) Values in 2018 dollars

Table 3-3: Summary of the National Database of Processed Post-2000 CoreLogic Building Data by Occupancy Class (2000 to 2018)

Occupancy	No. of Buildings	Total Square Footage (x1,000)	BRV ($M)(1)	CRV ($M)(1)
One- and Two-Family Dwellings	15,353,309	34,876,675	$5,540,045	$2,770,022
Other Residential	501,302	7,573,267	$1,286,597	$643,298
Commercial	678,382	9,017,148	$1,240,680	$1,267,923
Industrial	47,624	996,219	$121,075	$181,611
Other(2)	1,591,505	3,046,379	$323,076	$301,382
Total	**18,172,122**	**55,509,687**	**$8,511,473**	**$5,164,236**

(1) Values in 2018 dollars

(2) Other occupancies include agriculture, religion/non-profit, manufactured housing, education, and government uses

3.3.1 Accuracy and Gaps

This section is divided into CoreLogic data, building code data, and other types of data. Section 3.3.1.4 describes how the data gaps were filled.

3.3.1.1 CoreLogic Data

The primary CoreLogic data source for the BCS Study was based on assessor data from communities and other jurisdictions. The data had the following uncertainties to varying degrees: unknown update frequencies, unknown quality checks, varying data accuracy, transcription errors, and personal definitions of a given data field. Additionally, there were gaps in the CoreLogic database from a lack of available information (e.g., information lost due to improper documentation, information without documentation). Information gaps seemed to be on the county level, indicating that some counties are better at maintaining building construction history than others. A breakdown of the important data attributes and their percent completion per state are provided in Appendix A, Table A1-2, and per county in Appendix A, Table A1-3.

The CoreLogic dataset combined assessor data from communities and other jurisdictions nationwide into one file. Combining data can result in issues because data from different assessors may be incomplete, use different codes or platforms in each field, and/or the fields are interpreted differently (e.g., Year Built versus Effective Year Built). CoreLogic also aggregated some of the data into a single universal field (e.g., Universal Building Square Feet, Land Use), but the conversion of the assessor data into the universal categories was often difficult to understand or inconsistent. In addition, the data did not include the location of a building or buildings on the parcel, leading to imprecise locations of buildings on larger parcels if only CoreLogic data were used.

3.3.1.2 Building Code Data

Building code adoption data were generally obtained from the same or similar sources for the three hazards. The primary source was the ICC website, ICCSafe.org, which provided current state-level I-Code adoption status. This website was the most useful for statewide adoption and enforcement of current I-Codes and for information on where to find state-level code data.

Other sources were used for states that have not enacted code adoption and enforcement statewide. The sources were the 2015 and 2019 *National Building Code Assessment Report: Building Code Effectiveness Grading Schedule* (ISO, 2015; ISO, 2019). These reports contain current but limited historical information on statewide building code adoption. Further information was obtained through ISO State Fact Sheets (ISO, 2017; 2018a; 2018b) and by searching the internet for city and county municipal codes and ordinance adoption records. Local adoption information was verified using the BCEGS data that were obtained from ISO for purposes of the study.

Although useful in areas with less information on building codes, BCEGS only includes participating communities and is only updated every 5 years. The BCEGS building code data had gaps due to changes in building codes during the 5-year update gap. Without knowing when a building code changed, it was difficult to determine which building codes were in effect during the gaps or before a community was included within BCEGS. BCEGS scores were used as a reference, but each score represents a combination of all building code provisions, and individual code provisions that were adopted and the degree of code enforcement are not provided.

CRS data were used primarily to determine freeboard information. The CRS database has a problem that is similar to the BCEGS scores in that CRS is an aggregate of code scores of participating communities with little information on how the scores were tabulated or when provisions such as freeboard came into effect. It is possible that freeboard requirements are in building codes and that local floodplain management regulations are not included in the CRS database.

3.3.1.3 Additional Sources of Information

Additional sources of information included Microsoft Bing building footprint polygons and hazard maps, such as the NFHL, ASCE wind speed maps, and the USGS Ground Acceleration maps. The accuracy of the information varied. The footprint polygons provided more robust additional data than the hazard maps and allowed the identification of building locations within parcels for most of the parcels across the country, but the building footprints did not include additional attribute information (e.g., type of building, building height) about the buildings. In order to account for the unknown types of buildings represented by the footprints, they were then filtered, removing footprints smaller than 500 square feet to remove most of the miscellaneous footprints that represented sheds and patios.

Most of the older hazard maps were produced on regional or national scales without regard to local conditions. The maps were digitized as needed for the study. The digitization, combined with the initial production of the maps on a large scale, resulted in a degree of uncertainty, especially near the primary contours. Slight differences between projections also played a minor role in data uncertainty. Expert judgment was used to maintain a consistent level of accuracy and quality relative to the contribution the maps made to the model and outcome.

3.3.1.4 Gap Filling

The primary, and most robust, source of information for the study was the CoreLogic dataset, which contained approximately 147 million parcel records from across the United States. The dataset provided information such as building size, assessment value, construction material, and year built. However, there were significant gaps in the data that needed to be filled for the BCS Study analyses. The gaps were filled by replacing or supplementing the data.

The sources of information that were used to replace attributes of the CoreLogic data for all of the hazards were location information from state and county GIS data, Hazus census block, and census tract location information. Additional location information was derived from FEMA sources, including the community political areas from the National Flood Hazard Layer databases; however, these sources often had missing information or no information in some portions of a county.

The primary source of supplemental information was the Microsoft Bing building footprint data, which covered 80% of the post-2000 construction parcels. The footprint data had two benefits. The first was that it vastly improved the location of buildings in parcels by providing the building footprint location instead of just the general parcel boundaries. This information had the most significant impact on the flood analyses due to the highly precise changes in flood zones, but precise location information was also important in the seismic and hurricane wind analyses. The second benefit was that the data were used to verify and improve the building count on parcels. Although the CoreLogic data lists the number of buildings on a parcel, the footprint data made it possible to verify or correct this information. Incorrect building counts in the CoreLogic data were identified in 9% of the nationwide parcels.

The other supplemental data for all of the hazards were BRVs, CRVs, and number of stories. In the CoreLogic database, approximately 83% of the parcel records had the number of stories (76% in seismic states), and 17% was unusable without this information. Therefore, the analyses for all three hazards used generalized stock mapping schemes, Hazus default assumptions, or data-specific proxy approaches for selected building types (e.g., large buildings of certain occupancies in the seismic assessment; see Appendix F, Section F.3.2.1). In some instances, it was deemed necessary to determine the number of stories on a case-by-case basis using internet searches.

For the flood analyses, the foundation information in the CoreLogic database was not valid and was replaced with Hazus default assumptions based on location and specific occupancy. The hurricane wind analyses needed construction type and garage information. Since construction type was so poorly populated in the CoreLogic database, the hurricane general building stock mapping schemes in Hazus were used. When CoreLogic data did not have garage information, additional information from Hazus was used. The seismic analyses did not require additional gap filling before the building data could be assigned a model building type and used in the analyses. Figure 3-6 presents the percentages of the CoreLogic data that needed to be augmented for each data attribute applicable to each hazard.

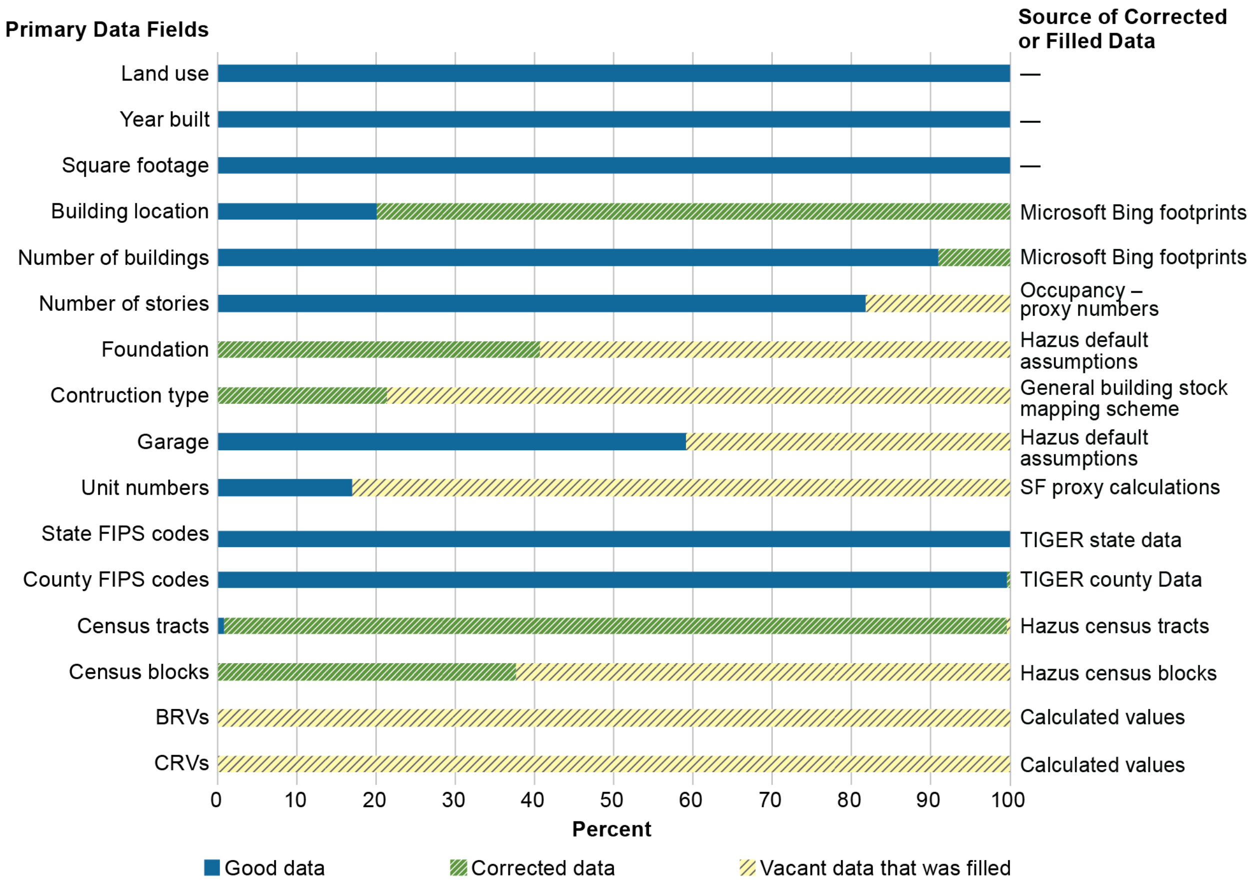


Figure 3-6: CoreLogic data percentage and amount of gap filling

3.3.2 Data Processing and Quality Control

The primary goal of the data processing was to enhance the features of the CoreLogic data, repair the inconsistencies and errors in the database when possible, and render the data usable for the losses avoided calculations. To provide the best data, the CoreLogic dataset, which is at the parcel scale, was combined with the Microsoft Bing building footprint polygon dataset to increase the granularity of the data to the building scale. Communities, counties, and states treat their data differently, so when the data are combined on a nationwide scale in the CoreLogic database, there are often inconsistencies across regions and even across counties and communities. The inconsistencies led to problems in finding one process that treated data from every state, county, and community consistently because the data can vary significantly. These inconsistencies resulted in processing the data through the ArcGIS platform and also the Amazon Web Server (AWS) platform, which produced two comparable datasets that could be cross checked, which helped to identify and reconcile data quality issues. The ArcGIS and AWS processes are described in Appendix C.

Validating data by comparing and cross checking between the ArcGIS and AWS platform processes and results provided a useful means of identifying and addressing discrepancies. Cross checks included:

- Confirming that the definitions of fields in the two platforms were consistent and identifying any differences in the intermediate fields that were developed
- Confirming that the data fields and attributes in the two datasets were consistent in terms of the number of fields that were populated and their values, investigating and documenting any significant differences, developing remedies, and implementing remedies where possible
- Determining that the differences in the final results for common attribute fields in the AWS and ArcGIS platforms were within acceptable tolerance levels appropriate for use as input to the Hazus computation and post-analytics assessments

An in-depth discussion on the data processing, validation, results, and quality control can be found within Appendix C.

An infographic depiction of the data assemblage and processing in preparation for hazard specific Hazus input formatting and computations is presented in Figure 3-7.

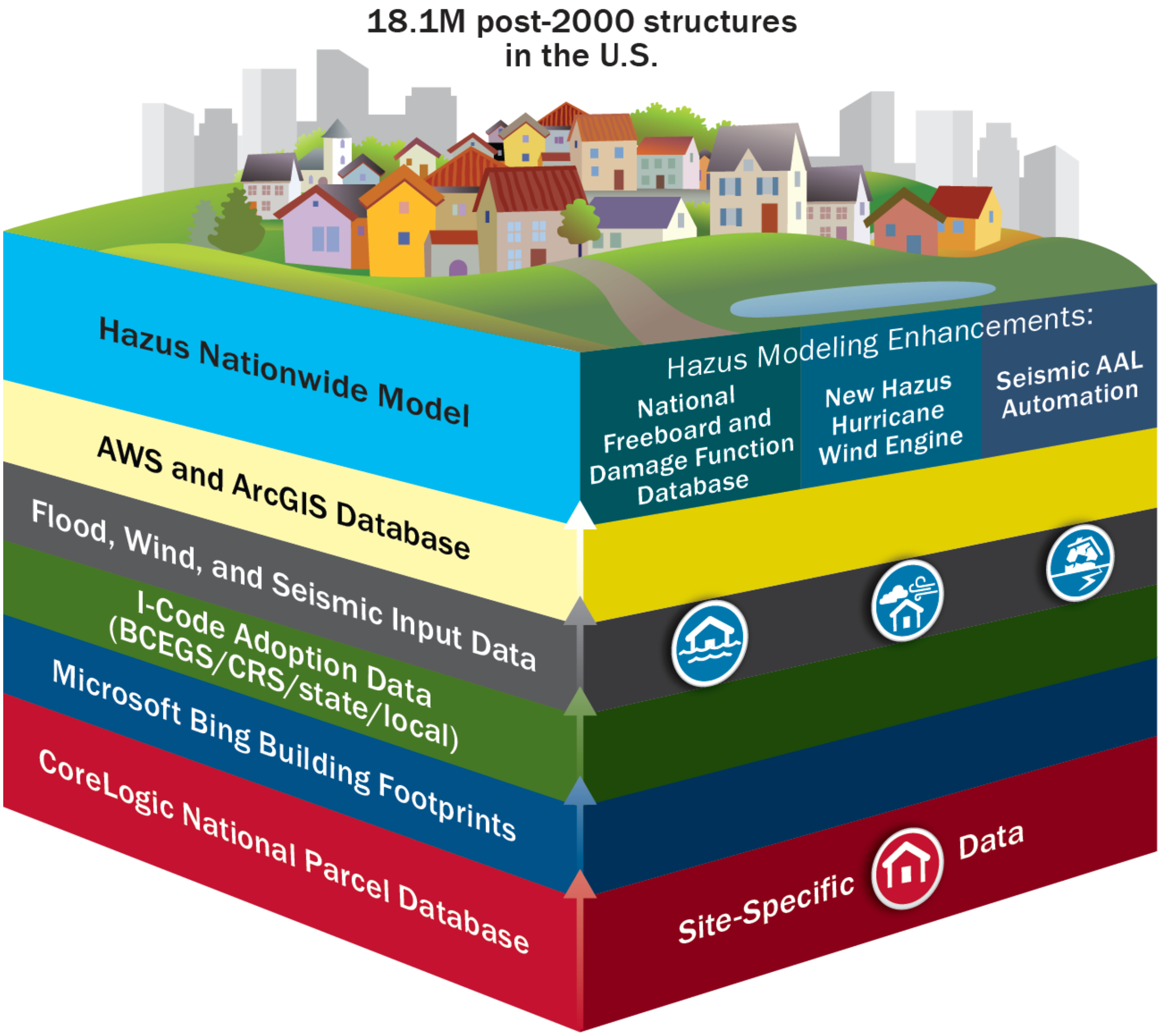


Figure 3-7: BCS losses avoided modeling database assemblage and processing visualization (concept after RMS)

CHAPTER 4

Flood Hazard Analysis

Average annual flood losses avoided for buildings and contents were modeled for approximately 786,000 buildings constructed from 2000 to 2018 and located in FEMA SFHAs across the nation.

The primary challenges in the flood hazard portion of the BCS Study were determining which of the structures in the FEMA SFHA likely had freeboard, what was a reasonable approximation of the flood zone and flood profile, and what available flood damage relationships should be used for modeling.

Chapter 4 presents an overview of the flood hazard analysis that was used to estimate the losses avoided when communities adopt a freeboard requirement for building in the SFHA. The main components of the analysis methodology were:

- **Flood code adoption**: Determining which communities had adopted freeboard from state data, Community Rating System (CRS) data, and local data
- **Flood hazard data**: Determining which structures were mapped within the FEMA SFHA and estimating the flood profile
- **Flood modeling data**: Determining which flood Depth-Damage Functions (DDFs) applied to each structure and calculating AALA related to building and contents damage

Freeboard

Freeboard is an additional height above the base flood elevation (BFE) that buildings are elevated to. Freeboard provides an increased level of flood protection and also acts as a factor of safety to compensate for uncertainties in the determination of flood elevations. Freeboard results in reduced flood insurance premiums.

Figure 4-1 is a flowchart of the flood methodology that shows how the CoreLogic post-2000 building inventory data were supplemented by flood data sources to create the databases that were used in the flood hazard analysis.

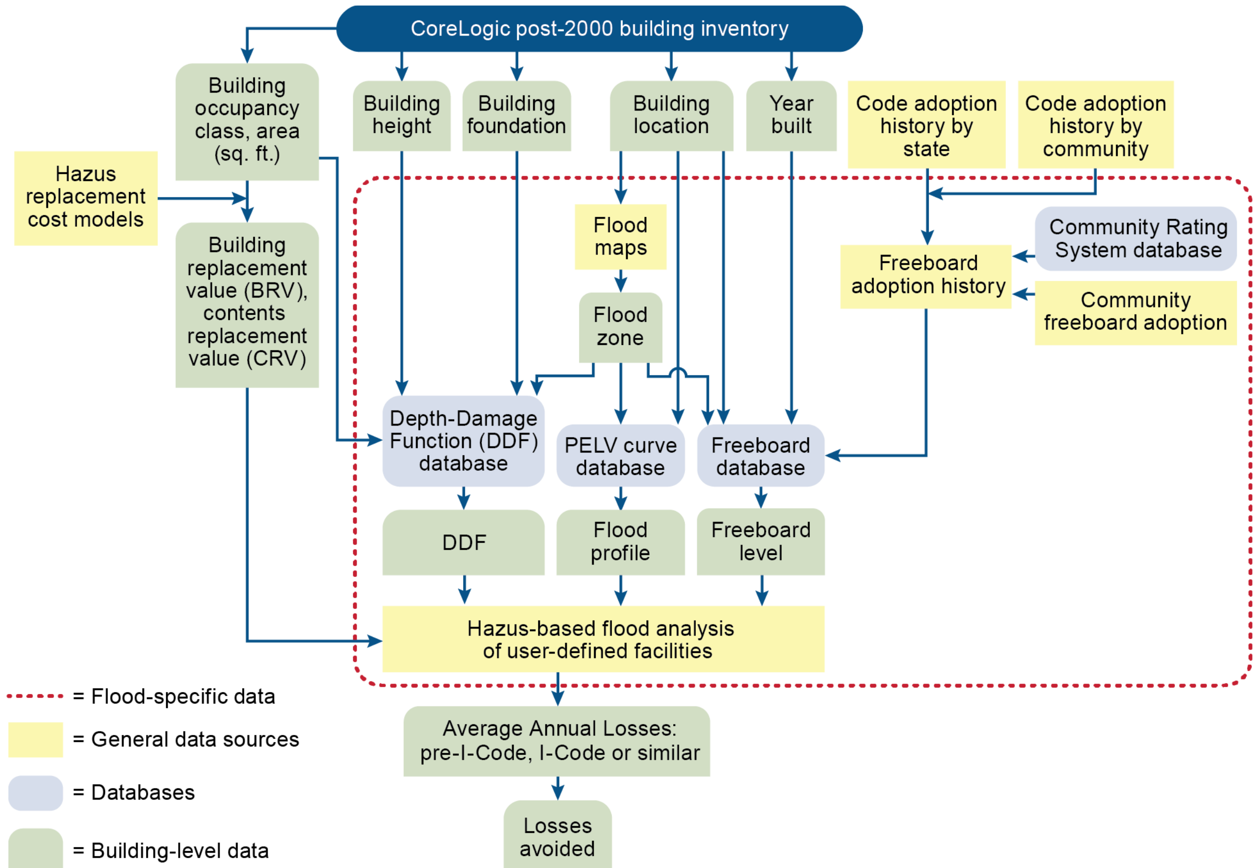


Figure 4-1: Flood methodology

4.1 Flood Code Adoption

The first component of the flood hazard analysis consisted of identifying a flood-resistant design metric that would represent all or part of the above-minimum NFIP design standards and then identifying the communities that have adopted the metric. Section 4.1.1 explains why freeboard was selected as the metric to represent I-Code and similar code requirements, and Section 4.1.2 describes how freeboard data were obtained from a variety of sources, including state code adoptions data (especially from the Association of State Floodplain Managers [ASFPM]), CRS data, BCEGS data, and additional local data).

For more information on flood requirements for structures in the NFIP and I-Codes, see Appendix D, Section D.1.1.

4.1.1 Selection of Freeboard as Primary Modeling Practice

The flood modeling in the BCS Study was scoped to include post-2000 building construction in the FEMA SFHA, which represents construction in locations where floodplain management ordinances are in effect. The modeling focused on building components that are representative of above-minimum NFIP design standards for post-Flood Insurance Rate Map (post-FIRM) construction. Post-FIRM construction occurs in a community after the community joins the NFIP and adopts an NFIP-compliant local floodplain management ordinance that includes the first series of community FIRMs. Based on a review of local assessor data and CoreLogic parcel data, the available data were not adequate to determine the presence of specific above-minimum NFIP design components required by the I-Codes (e.g., lowest floor elevation [LFE], elevated utilities, coastal design components such as breakaway walls) at the structure level.

Data availability was also an issue in the available DDFs, primarily from Hazus. The DDFs only took into account structure usage (Hazus Occupancy Categories; see Table 3-1) and general flood zones (Zone AE versus Zone VE) over a range of flood depths in structures, but did not have sufficient resolution to indicate the absence or presence of most of the above-minimum NFIP design components.

These limitations required identifying a flood-resistant design metric that would represent all or part of the above-minimum NFIP design standards, ideally those represented in the I-Codes. Freeboard was selected as the metric that would allow modeling from available data sources. See Appendix D, Section D.1.1, for a description of how freeboard requirements evolved for both the IBC and IRC. The IBC has included freeboard provisions since 2000 for some IBC structure types and for most IBC structure types since 2006. The IRC freeboard has gone from not being required to being partially required; and finally, in the 2015 and 2018 editions, to always being required.

Freeboard acts as an indicator of above-minimum flood-resistant design; the year 2000 was selected as the baseline because freeboard was not included in either the NFIP regulations or the I-Codes in 2000. Modeling freeboard synthesized the use of available DDFs and structure data. Most DDFs have resolution at every foot of flood depth, which allowed modeling to generate different loss values for typical freeboard levels such as 1 foot above the BFE. Likewise, the assumption of without-freeboard construction having the LFE at the NFIP minimum BFE (associated with a 1-percent-annual-chance event) (see Figure 4-2) allowed losses to be calculated without having to compile or derive detailed hydrologic and hydraulic modeling for every structure location. Therefore, the decision was made to focus the flood methodology on freeboard modeling.

Two assumptions were required to develop nationwide freeboard data within the study's time frame. One was to focus on residential construction data sources, when needed, when identifying sources of freeboard adoption data. Hazus default data for all structures shows that more than 80% of structures are residential structures and almost all of them fall under the IRC.

Some sources, such as the FEMA CRS and local freeboard ordinances, usually do not make a distinction between residential and non-residential structures in freeboard data. In contrast, data sources based only on IRC or IBC freeboard provisions have differences in required freeboard for the small percentage of structures that fall under the IBC (see Appendix D, Table D-2, for the Hazus Occupancy Classes that correspond to IBC or IRC standards). In Table 3-1 for almost all

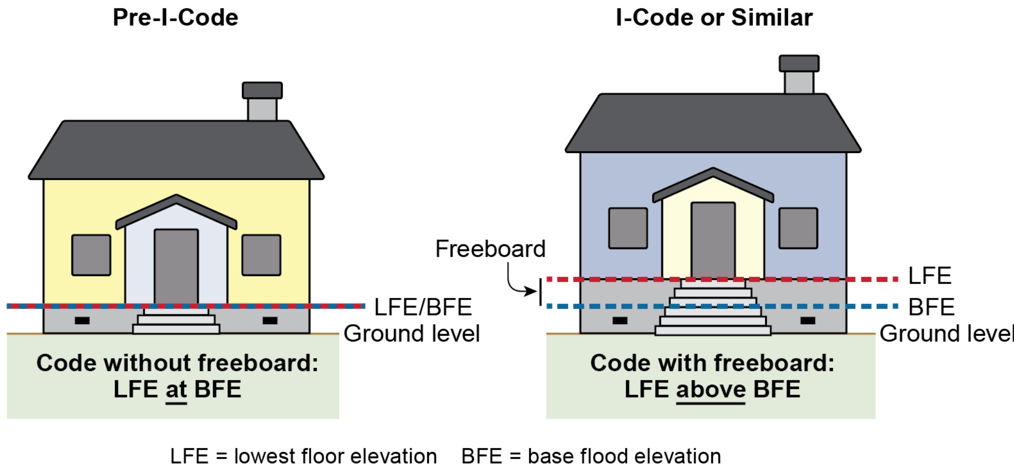


Figure 4-2: Freeboard assumptions in the BCS Study for riverine structures

cases, the IBC freeboard is the same or greater than the IRC freeboard. In balancing available resources for the study, the decision was made to focus on leveraging other freeboard data sources, especially the FEMA CRS database, rather than directly accounting for IBC-only freeboard adoption. This assumption is revisited at the end of this chapter and includes structure counts based on the assumption.

The second assumption was that manufactured housing units would be excluded from the flood analysis because of the way manufactured housing units are regulated and also data limitations. See Appendix D, Section D.1.1.3, for more information on the exclusion of manufactured housing from the flood analysis.

4.1.2 Sources of Freeboard Adoption Data

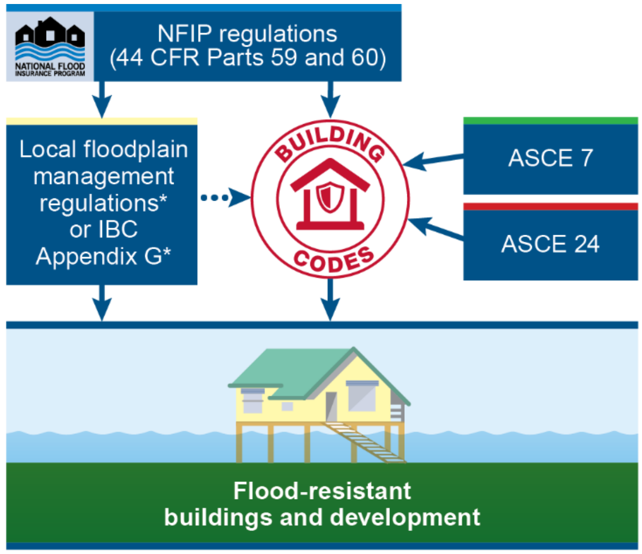
The FEMA CRS was the primary source of national freeboard adoption data. Other sources were national databases of code adoption such as BCEGS (ISO, 2019), ASFPM surveys on freeboard adoption (primarily state-level adoption) (L.R. Johnston Associates, 1992; ASFPM, 2004; ASFPM, 2015), and state-provided local freeboard adoption information.

Freeboard Database

The freeboard database was developed from the following:

- FEMA CRS data
- State code adoption data (primarily from ASFPM)
- BCEGS data
- Additional local data

The need to use multiple data sources to estimate freeboard levels nationwide is based on the fact that floodplain management regulations across communities are complex. As shown in Figure 4-3, floodplain regulations are based on NFIP regulations and reference standards such as ASCE 7 and ASCE 24, which are adopted by reference in building codes such as the I-Codes. Freeboard requirements can be based on many possible sources, and freeboard can be established as a requirement in both building codes and local floodplain management regulations.



* NFIP-consistent administrative provisions, community-specific adoption of FISs and maps, and technical requirements for development outside the scope of the building code (and higher standards in some communities)

Figure 4-3: Sources of floodplain management regulations

Because of the complex relationship between regulatory provisions and codes, the code or regulation statement that is used to establish freeboard may reside in any of the following:

- State regulations
- State code (default I-Codes or modification to codes)
- Local regulations
- Local codes (default I-Codes or modification to I-Codes and/or state codes)

To develop a freeboard database for the study, the three primary data sources of state-level, CRS, and local data were combined to produce estimates on a year-by-year basis from 2000 through 2018 of freeboard levels at the NFIP community (sub-county) level for Zone A and Zone V areas.

Appendix D, Section D.1, describes the approaches that were used for each type of data source. Appendix D, Section D.1.2, provides details on the use of data sources from BCEGS, ASFPM, and CRS. Appendix D, Section D.1.3, includes an overview of the major steps in converting the FEMA CRS database into a format that was usable in the study. Appendix D, Section D.1.4, lists the states in which local freeboard data were provided to FEMA for the study. Finally, Appendix D, Section D.1.5, describes the freeboard database that was developed by combining all of the data sources.

The freeboard adoption data that were developed for the study could be organized in many ways. It was decided to divide the 50 states and Washington, DC, into three categories of freeboard adoption based on when freeboard was adopted statewide. The categories are described below and shown in Figure 4-4.

Freeboard Adoption Categories

The BCS Study divided states into the following three freeboard adoption categories:

- Innovator: Statewide freeboard in 2000 or earlier
- Emergent: Statewide freeboard after 2000
- Limited: Only community-level freeboard

- **Innovator: Statewide freeboard in 2000 or earlier** (15 states and Washington, DC). Innovator states are states in which the available data sources indicate that statewide freeboard requirements have been in place since at least 2000. The freeboard requirements are in some portion of state regulations, and the states tend not to use modified IRC standards to establish freeboard requirements. Most of the ASFPM and CRS sources indicated that Innovator states have had freeboard requirements for a long time.
- **Emergent: Statewide freeboard after 2000** (14 states). Emergent states are states in which the available data sources indicate that statewide freeboard requirements were adopted after 2000. Emergent states tend to use modified standards in IRC editions prior to the 2015 edition to establish freeboard requirements.
- **Limited: Community-level freeboard only** (21 states). Limited states are states in which the data sources indicate that freeboard requirements have been adopted only at the community level. Limited states include states with no statewide IRC adoption or optional local IRC adoption, IRC adoption of editions prior to 2015 when freeboard was not required, and IRC adoption of 2015 or 2018 editions where freeboard requirements have been removed.

The trends in the three categories are as follows:

- Innovator states have the most widespread freeboard adoption, as indicated by the number of communities with freeboard, and the highest relative average community freeboard from 2000 to 2018. Many of the communities in these states, as indicated by the CRS data, adopted freeboard standards that are higher than the state minimums.
- Emergent states are the middle category for freeboard adoption. Many of the Emergent states transitioned to statewide requirements after 2010, so they were expected to have a lower percentage of floodplain structures with freeboard than Innovator states. Likewise, most of the communities in these states adopted the IRC minimum 1.0-foot freeboard, so the average freeboard level was expected to be lower than the average level in Innovator states.
- Limited states have by far the lowest percentage of communities with freeboard. In many of the states, the number of communities with freeboard is less than 10% of the communities without freeboard. However, in the few communities with freeboard, the average freeboard level often exceeds the average in Emergent states.

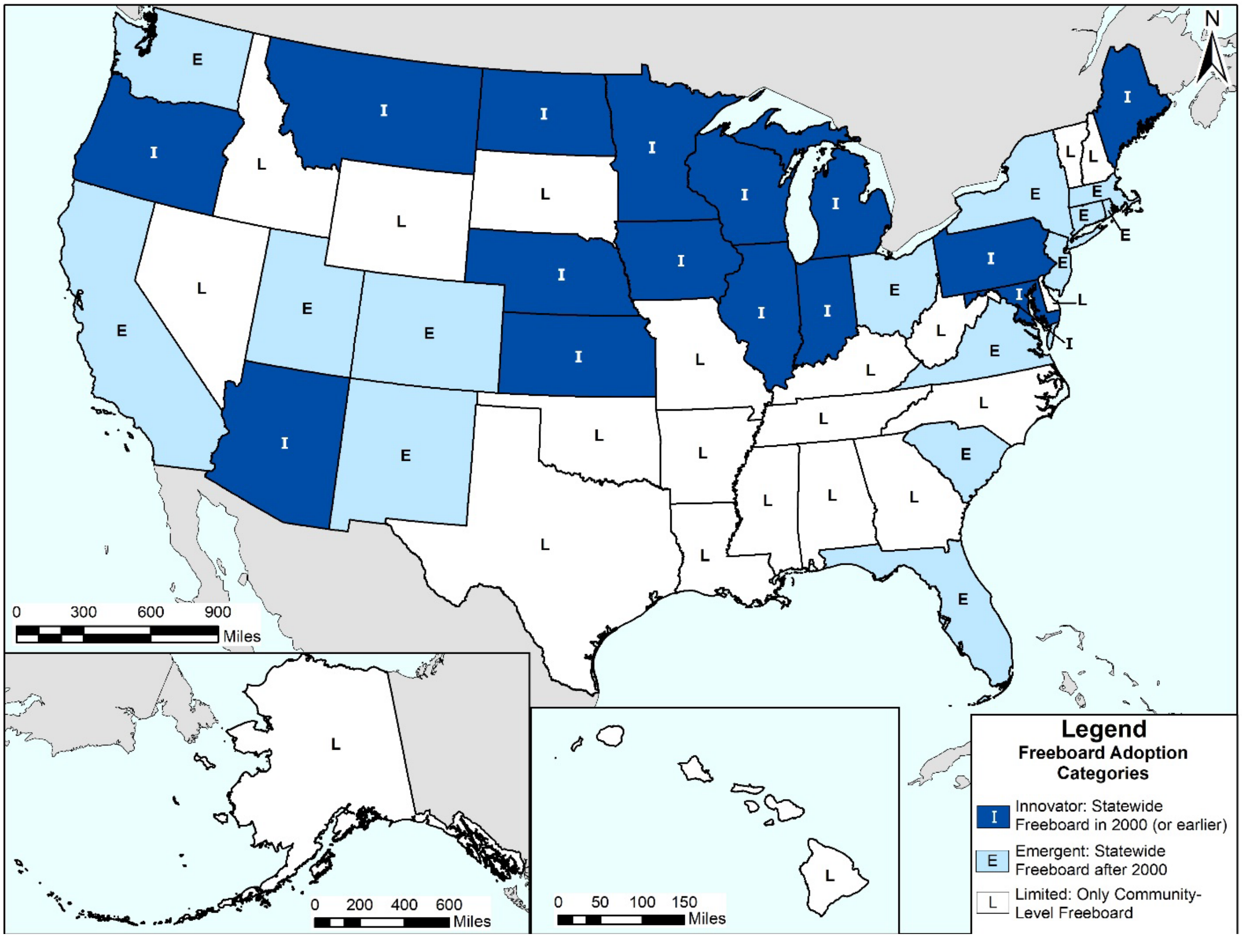


Figure 4-4: Freeboard adoption categories by state

4.2 Flood Hazard Data

The second component of the flood hazard analysis was assigning structures as in or out of the NFIP floodplain and assigning a representative flood profile to each structure. Using the latest available digital floodplain data, along with flood profile information from historical flood insurance policy data, the BCS Study was able to approximate flood profiles nationwide without having to conduct new, extensive floodplain modeling.

Flood Hazard Data

The flood hazard data that were required for the BCS Study included:

- NFIP floodplain mapping (identification of structures in or out of the floodplain)
- Flood profiles (estimated flood depths over a range of percent-annual-chance events)

4.2.1 Flood Hazard Mapping

One critical dataset for establishing what structures may have freeboard is flood boundary data; specifically, FEMA flood zones and FEMA community boundaries as represented by FEMA Community Identifications (CIDs). Flood hazard data related to FEMA flood hazard zones and BFEs for structures designed after 2000 were obtained primarily from the NFHL dataset, which is maintained by FEMA as part of the NFIP. The dataset includes the current effective flood hazard data for the areas of the country where flood maps have been modernized to a digital format. It also includes political boundary data to establish the CIDs. The dataset is a compilation of effective FIRM databases and Letters of Map Change. In non-NFHL areas, the best available SFHA mapping from CoreLogic was also used.

Flood zone data were used in two ways. First, the geographic boundaries of the zones were used to identify which structures are in the SFHA. Second, the data were used to assign structures to a Zone A or Zone V flood hazard area; the zone affects the DDFs that are used to estimate flood damages for a parcel. The flood analysis included the structures built after the year 2000 and located in the SFHA. The use of Microsoft data in the BCS Study helped to overcome CoreLogic structure location issues in which the structure location was based only in the centroid of tax parcels. By using available Microsoft data to correctly locate structure points within the structure footprint, uncertainty about structures being falsely included in the analysis was greatly reduced.

4.2.2 Flood Profile Modeling

Modeling the flood hazard included horizontal considerations of inside versus outside the SFHA and vertical considerations of the flood profile in a given location for a structure of interest. Damage severity to a structure from flooding is related to the depth or elevation of floodwater.

Since the 1970s, actuarial methods in the NFIP have used the water depth probability curve or Probability of Elevation (PELV) Curves. Each PELV Curve represents a range of probabilities versus the floodwater elevations in relation to the BFE. On older FEMA mapping, PELV Curves were represented by labeling flood zones with “A” or “V” followed by a number. The old numbered flood zones A1–30 and V1–30 were assigned based on PELV. For example, A2 represented a curve where the elevation difference between the 10-year (10-percent-annual-chance-event) and the 100-year (1-percent-annual-chance-event) represented 1 foot, and the relative elevations of other events could be found from a log curve fit through these two known events.

Figure 4-5 shows the flood profiles for three example PELV Curves, where the LFE is set at the 100-year flood elevation. In addition to the A2 PELV Curve, A5 represents a 2.5-foot difference, and A10 represents a 5.0-foot difference between the 10-year and 100-year flood elevations.

Figure 4-6 through Figure 4-8 show examples of Zone A PELV Curves from older FEMA maps for a variety of riverine conditions.

In coastal areas, the PELV Curve value becomes more complex. Zone A and Zone V are shown side-by-side as wave heights decrease below the 3-foot threshold for Zone V (see Figure 4-9).

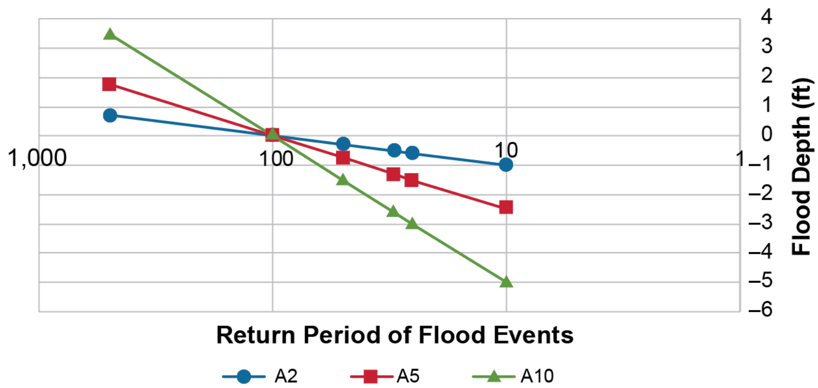


Figure 4-5: PELV Curves examples for A2, A5, and A10 with 100-year event at LFE

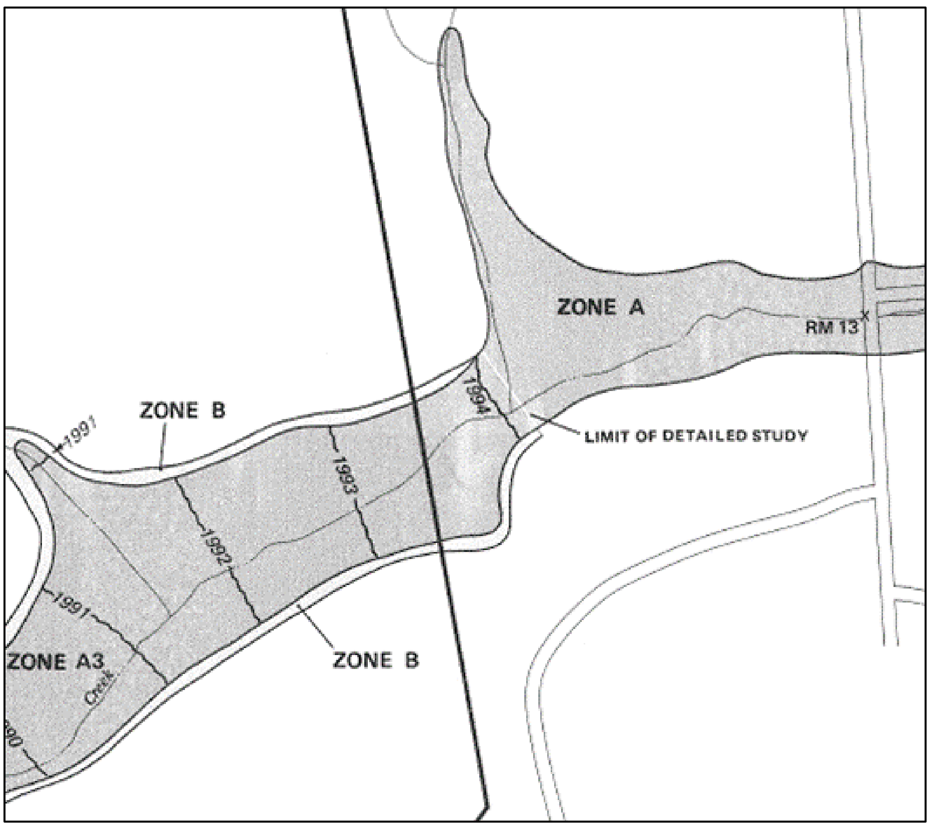


Figure 4-6: Riverine Zone A3 PELV Curve example

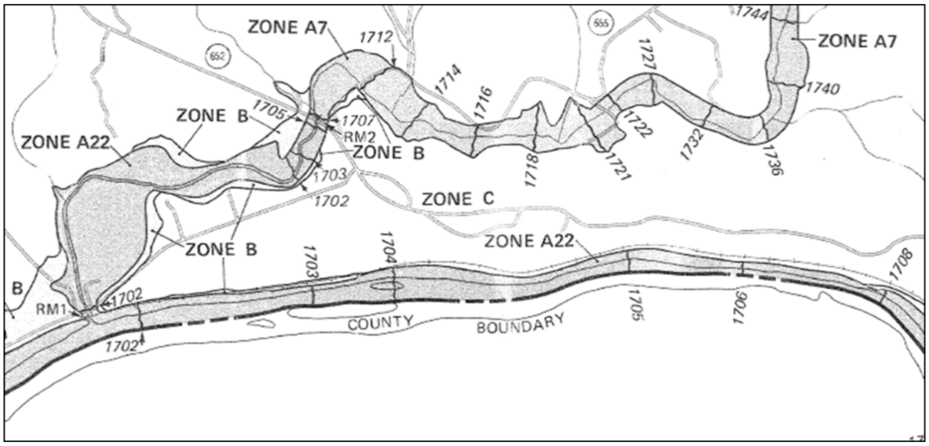


Figure 4-7: Riverine Zone A7 and Zone A22 PELV Curve example

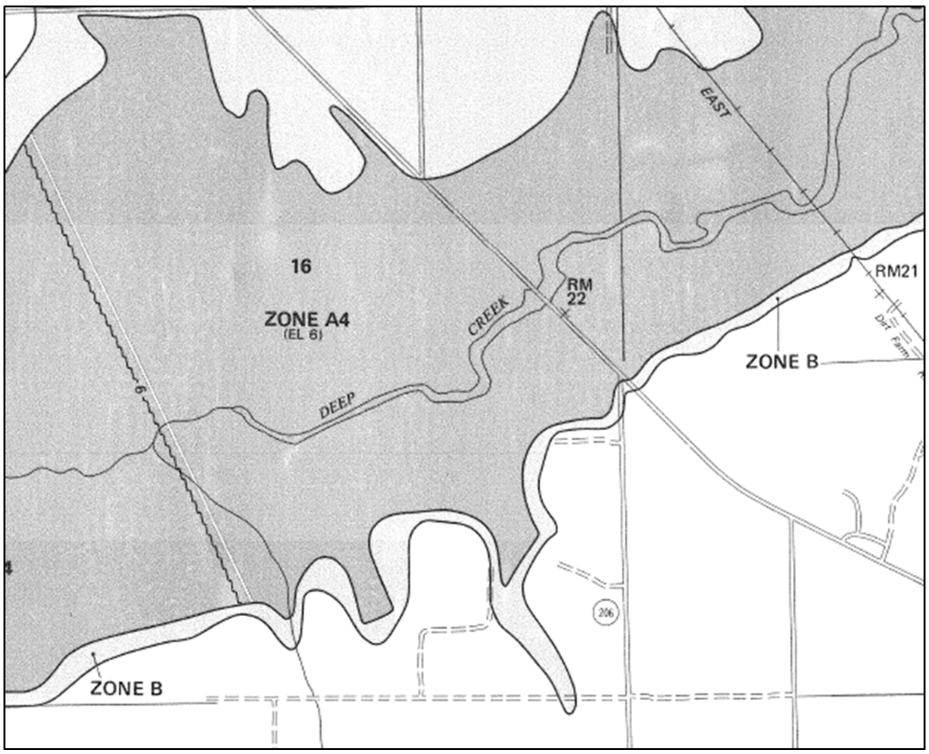


Figure 4-8: Riverine stillwater Zone A4 PELV Curve example

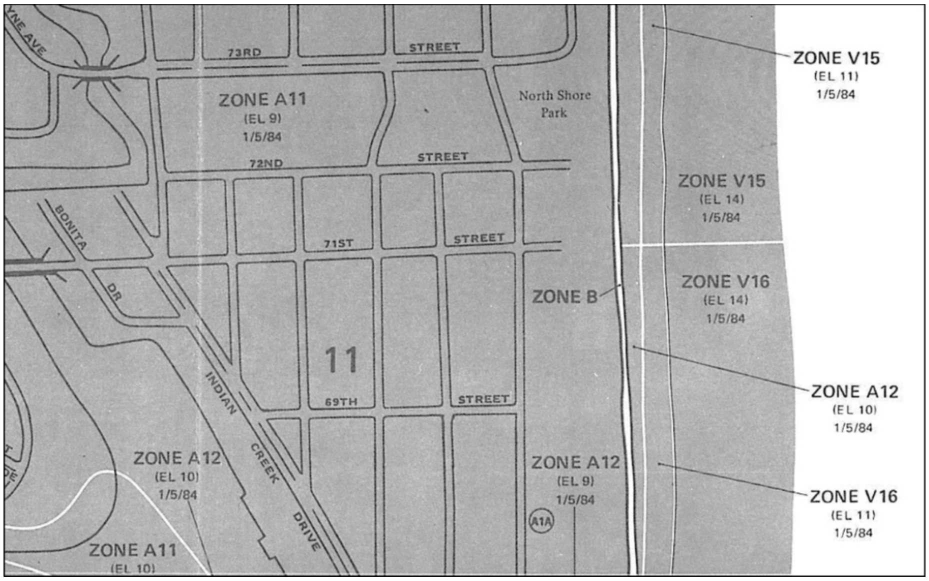


Figure 4-9: PELV Curves in coastal areas

In general, Zone A PELV Curve trends tend to be the following:

- Low PELV Curve values (A4 and less) are seen in small-drainage upstream areas and in downstream, flatter sloped areas near confluences or the ocean.
- Middle PELV Curve values (A5 to A12) are the most frequent values seen for typical riverine areas over a wide range of drainage and slope conditions and may be seen in the inland portion of some coastal flood areas.
- High PELV Curve values (A13 and above) are seen in higher sloped, larger drainage rivers (especially in the mountains) and in coastal areas.

For Zone V PELV Curves, nationally, the West Coast states tend to have lower values than Gulf of Mexico and East Coast states.

Obtaining PELV Curve data nationally was a challenge. No public datasets were available that included PELV Curves other than the historical FIRM panel graphics. In June 2019, FEMA published 10 years of NFIP policy data, redacted to mask Personally Identifiable Information. This dataset included PELV Curve data for a portion of the policies and was used to develop a national PELV Curve database with PELV Curve statistics. The most detailed geographic unit for which PELV Curve statistics could be summarized was the census tract. Although the policy data covered about 99% of all 2010 census tracts, only 30% had PELV Curve data. For the remaining 70%, the county PELV Curves statistics (where available) or the state PELV Curve statistics (shown in Appendix D, Section D.2.1) were used.

All of the structures modeled in the study were assigned a flood profile using the PELV Curve approach. The calculation assumption, as shown in Figure 4-1, is that all structures apply freeboard to a LFE value in which the LFE is set at the BFE. For the structures that did not have

BFE values in mapping and background flood studies and for structures that were mapped in Zone A or V (also called approximate or unnumbered zones), not Zone AE or VE, the actual LFE is likely below the 1-percent-annual-chance elevation. Because of the excessive additional data requirements, the actual LFEs were not estimated for these structures. Therefore, losses avoided are underestimated for these structures when using the BFE-at-LFE assumption.

PELV Curve data represented the best available national flood profile data for the study. Although future FEMA efforts in modeling multiple percent-annual-chance events may produce a new national level database, for the BCS Study, the existing PELV Curves provided a consistent national dataset to approximate flood profiles. Additional details on the process used for the PELV Curve data are presented in Appendix D, Section D.2.2.

4.3 Flood Modeling Methodology

The third component of the flood hazard analysis methodology was assigning the flood DDF to structures. Selecting the most appropriate DDF included comparing the best available data on flood hazard and structure characteristics (e.g., occupancy, number of stories, foundation information) to a library of DDFs.

Appendix D, Section D.3.1, contains additional details on the flood data field derivations for the number of stories and foundation types.

Flood Depth-Damage Functions

Flood DDFs were selected using the following data:

- Flood hazard zone
- Type of occupancy
- Number of stories
- Foundation types

4.3.1 Flood Depth Damage Functions

For the BCS Study, DDFs were drawn primarily from new structure DDFs (mainly residential) from FEMA's Coastal Probabilistic Flood Risk Analysis (PFRA) efforts and from non-residential structure DDFs that were developed for the BCS Study. In addition, the analysis developed new contents DDFs for both the new residential and non-residential DDF types. Residential DDF development is presented in Appendix D, Section D.3.2.1, and details related to the development of the other DDFs are provided in Appendix D, Section D.3.2.2.

4.3.1.1 Summary of DDFs

Table 4-1 lists the DDFs that were considered for each single-family dwelling (RES1) structure, and Table 4-2 lists the default DDFs for the other occupancies modeled in the study. Finally, Table 4-3 lists the default DDFs for each Hazus Occupancy Classification. Note that manufactured housing (RES2) structures are excluded because they were not included in the study (see Appendix D, Section D.1.1).

Table 4-1: Single-Family Dwelling (RES1) DDF Master List

BCS DDF Number	DDF Description
1	SFH 1-story shallow freshwater riverine inundation
2	SFH 2-story shallow freshwater riverine inundation
3	SFH 1-story unfinished basement freshwater riverine inundation
4	SFH 2 1-story unfinished basement freshwater riverine inundation
5	SFH 1-story finished basement freshwater riverine inundation
6	SFH 2-story finished basement freshwater riverine inundation
7	SFH 1-story deep freshwater riverine inundation
8	SFH 2-story deep freshwater riverine inundation
21	SFH 1-story shallow 3-foot wave and greater saltwater inundation
22	SFH 2-story shallow 3-foot wave and greater saltwater inundation
23	SFH 1-story unfinished basement 3-foot wave and greater saltwater inundation
24	SFH 2-story unfinished basement 3-foot wave and greater saltwater inundation
25	SFH 1-story finished basement 3-foot wave and greater saltwater inundation
26	SFH 2-story finished basement 3-foot wave and greater saltwater inundation
27	SFH 1-story deep 3-foot wave and greater saltwater inundation
28	SFH 2-story deep 3-foot wave and greater saltwater inundation

Table 4-2: All Other Building Types (Non-RES1) DDF Master List

BCS DDF Number	DDF Description
9	Apartment freshwater riverine inundation
10	Office 1-story freshwater riverine inundation
11	Office 3-story freshwater riverine inundation
12	Retail freshwater riverine inundation
13	Hospital freshwater riverine inundation
14	School freshwater riverine inundation
15	Police freshwater riverine inundation
16	Hazus Default COM10-Parking Zone A
17	Hazus Default IND1-Heavy Zone A
18	Hazus Default IND2-Light Zone A
29	Apartment 3-foot wave and greater saltwater inundation
30	Office 1-story 3-foot wave and greater saltwater inundation
31	Office 3-story 3-foot wave and greater saltwater inundation
32	Retail 3-foot wave and greater saltwater inundation
33	Hospital 3-foot wave and greater saltwater inundation
34	School 3-foot wave and greater saltwater inundation
35	Police 3-foot wave and greater saltwater inundation
36	Hazus Default COM10-Parking Zone V
37	Hazus Default IND1-Heavy Zone V
38	Hazus Default IND2-Light Zone V

Table 4-3: DDF Assignments by Occupancy

Hazus-Specific Occupancy	Occupancy Description	Flood Zone	BCS Study DDF Number
RES1	Single-Family Dwelling	A	1 through 8
RES3A	Multi-Family Dwelling – Duplex	A	2
RES3B	Multi-Family Dwelling – 3-4 Units	A	2
RES3C	Multi-Family Dwelling – 5-9 Units	A	9
RES3D	Multi-Family Dwelling – 10-19 Units	A	9
RES3E	Multi-Family Dwelling – 20-49 Units	A	9
RES3F	Multi-Family Dwelling – 50+ Units	A	9
RES4	Temporary Lodging	A	9
RES5	Institutional Dormitory	A	9
RES6	Nursing Home	A	9
COM1	Retail Trade	A	12
COM2	Wholesale Trade	A	12
COM3	Personal and Repair Services	A	12
COM4	Business/Professional/Technical Services	A	11
COM5	Depository Institutions	A	10
COM6	Hospital	A	13
COM7	Medical Office/Clinic	A	10
COM8	Entertainment & Recreation	A	10
COM9	Theaters	A	10
COM10	Parking	A	16
IND1	Heavy	A	17
IND2	Light	A	18
IND3	Food/Drugs/Chemicals	A	12
IND4	Metals/Minerals Processing	A	12
IND5	High Technology	A	12
IND6	Construction	A	12
AGR1	Agriculture	A	12
REL1	Church/Membership Organizations	A	10
GOV1	General Services	A	11
GOV2	Emergency Response	A	15
EDU1	Schools/Libraries	A	14
EDU2	Colleges/Universities	A	14
RES1	Single-Family Dwelling	V	21 through 28
RES3A	Multi-Family Dwelling – Duplex	V	28
RES3B	Multi-Family Dwelling – 3-4 Units	V	28
RES3C	Multi-Family Dwelling – 5-9 Units	V	29
RES3D	Multi-Family Dwelling – 10-19 Units	V	29
RES3E	Multi-Family Dwelling – 20-49 Units	V	29
RES3F	Multi-Family Dwelling – 50+ Units	V	29
RES4	Temporary Lodging	V	29

Table 4-3: DDF Assignments by Occupancy (cont.)

Hazus-Specific Occupancy	Occupancy Description	Flood Zone	BCS Study DDF Number
RES5	Institutional Dormitory	V	29
RES6	Nursing Home	V	29
COM1	Retail Trade	V	32
COM2	Wholesale Trade	V	32
COM3	Personal and Repair Services	V	32
COM4	Business/Professional/Technical Services	V	31
COM5	Depository Institutions	V	30
COM6	Hospital	V	33
COM7	Medical Office/Clinic	V	30
COM8	Entertainment & Recreation	V	30
COM9	Theaters	V	30
COM10	Parking	V	36
IND1	Heavy	V	37
IND2	Light	V	38
IND3	Food/Drugs/Chemicals	V	32
IND4	Metals/Minerals Processing	V	32
IND5	High Technology	V	32
IND6	Construction	V	32
AGR1	Agriculture	V	32
REL1	Church/Membership Organizations	V	30
GOV1	General Services	V	31
GOV2	Emergency Response	V	35
EDU1	Schools/Libraries	V	34
EDU2	Colleges/Universities	V	34

4.3.2 Modeling Procedure

Once all required data fields were populated for the flood analysis, the final step was conducting a loss analysis for the I-Code or similar (with freeboard) and pre-I-Code (no freeboard) scenarios. The pre-I-Code scenario has the elevation of the lowest floor to the BFE based on NFIP minimum requirements; the I-Code scenario has the elevation of the lowest floor to the BFE plus freeboard based on requirements in place at the time of construction, which varied based on building location and year built.

Flood Average Annual Losses

Flood AALs were calculated from losses in the following five events:

- 10-percent-annual-chance event
- 4-percent-annual-chance event
- 2-percent-annual-chance event
- 1-percent-annual-chance event
- 0.2-percent-annual-chance event

The study used a new cloud-based database replication of the Hazus Flood User-Defined Facility (UDF) model. Details on Hazus Flood UDF modeling can be found in the *Hazus Flood User Guidance* (FEMA, 2018c). In addition, because of the use of the PELV Curves, all five standard events from Hazus were modeled. The AAL equation from the *Hazus Flood Technical Manual* (FEMA, 2012d) is as follows (modified to use percent-annual-chance events rather than return periods):

$$AAL = 0.03{*}Loss_{10\%} + 0.040{*}Loss_{4\%} + 0.015{*}Loss_{2\%} + 0.009{*}Loss_{1\%} + 0.006{*}Loss_{0.2\%}$$

The weights on each loss value are the mathematical equivalent of a trapezoidal area method for the area under the curve. Therefore, to apply this equation, the losses for each structure must be calculated for the I-Code and pre-I-Code scenarios for each of the five events. The PELV Curve for each structure established the relative elevations of the flood profile for the five events. The pre-I-Code established the structure's LFE = BFE = 1-percent-annual-chance-event flood elevation. The I-Code used the same flood profile relative elevations, but now the LFE = BFE + freeboard. Therefore, when flood depth within a structure is calculated, all flood depths in the I-Code structure will be lower than the pre-I-Code structure by the freeboard level, as shown in Figure 4-10.

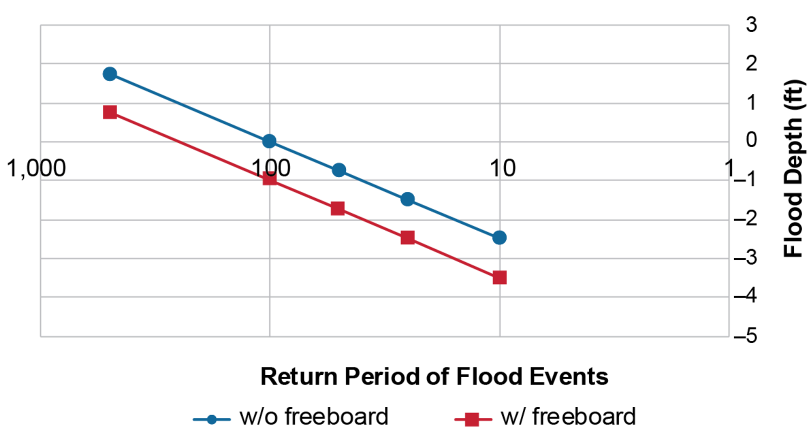


Figure 4-10: PELV Curve example with and without freeboard

These two sets of flood depths are then used with the DDFs to establish damage percentages for each event, as shown in Figure 4-11.

Finally, these damage values can be applied to the AAL equation (which derives the area under each line from Figure 4-11) to determine AALA values for that scenario. The entire process is used for structure damage and contents damage, which are then added together to produce the total AAL for that structure. The AALA value is then calculated as the I-Code AAL minus the pre-I-Code AAL. This is repeated for all structures.

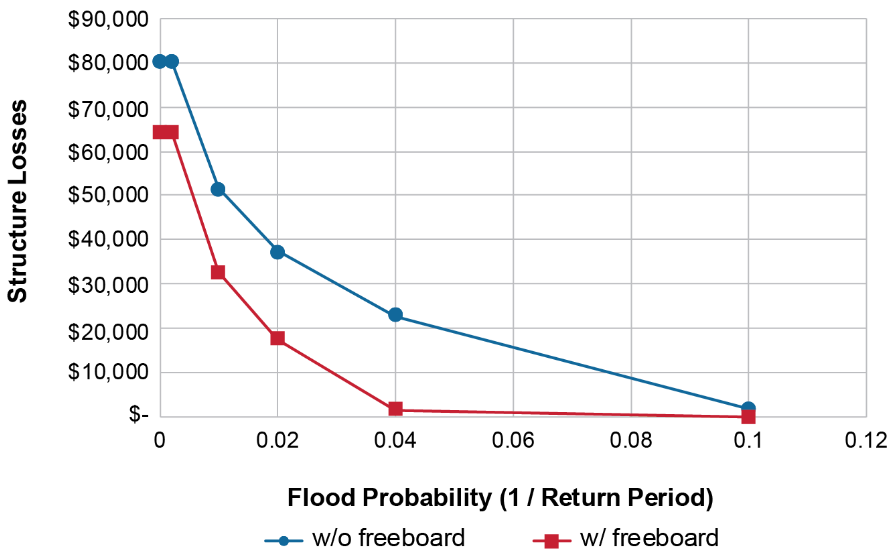


Figure 4-11: AAL calculation with and without freeboard

4.4 Flood Modeling Results

Flood modeling was conducted for all 50 states and Washington, DC. This section presents the results in two parts: first, results for California and Florida down to the county level, which show some of the trends in the two states, and second, nationwide results at the state level so that states can be compared. County-level results in this document are shown for California and Florida.

Flood Analysis Summary

- All 50 states and Washington, DC
- Approximately 786,000 post-2000 structures in the floodplain
- Approximately 400,000 structures (51%) had freeboard
- Total AALA: Approximately $484 million ($1,200 per freeboard structure)

County-level results for states other than California and Florida are provided in Appendix A. California and Florida were selected because California has the highest losses from the seismic hazard and Florida has the highest losses for the flood and hurricane wind hazards. For the flood hazard, the county-level results from both states show some of the major trends in all states.

4.4.1 County-Level Results: California and Florida Annual Losses Avoided

This section provides the following results for California and Florida at the county-level: results of the floodplain analysis, results of the analysis of the freeboard adoption data that were collected, and loss avoidance values.

4.4.1.1 Floodplain Analysis and Freeboard Adoption

The flood analysis was performed only on structures in the NFIP-designated floodplain. California and Florida provide a good contrast in the percentage of structures in the floodplain at the state level. Of the roughly 1.3 million structures in the post-2000 data for California, only 3% (around 45,000) were in the floodplain. In Florida, 1.7 million structures were in the post-2000 data, and approximately 19% (approximately 311,000) were in the floodplain. The reason for the large difference (3% versus 19%) is a result of both hazard (percentage of land area in the floodplain) and construction patterns (the portion of post-2000 construction that occurred in the floodplain).

For freeboard adoption, however, the states had a similar pattern. California had approximately 56% of floodplain structures (around 29,000) with freeboard, while Florida had approximately 48% of floodplain structures (around 150,000) with freeboard. The remaining structures in the SFHA were assumed to not have freeboard and were assumed to be built with the NFIP minimum requirement of the LFE at the BFE. The reason for the similar values is that both states had similar patterns of freeboard adoption in the post-2000 period (2000 to 2018). Initially, both states had only a small number of urban areas with mandatory freeboard, but the number of communities with freeboard increased over time until both states had adopted statewide freeboard requirements for all structures by requiring the adoption of the 2015 IRC and IBC.

California and Florida Trends

- Florida had higher post-2000 structures (1.7 million, second nationally) than California (1.3 million, third nationally)
- Florida had a much higher percentage of structures in the floodplain (311,000 or 19%) than California (45,000 or 3%)
- California had slightly higher percentage with freeboard (29,000 or 56%) than Florida (150,000 or 48%)
- Florida had higher AALA ($169 million, first nationally for flood) than California ($47 million, third nationally for flood)

4.4.1.2 Loss Avoidance Values

Table 4-4 shows the California county-level loss avoidance results, Table 4-5 shows the Florida county-level loss avoidance results, and Table 4-6 shows selected California and Florida results by occupancy.

Table 4-4: California County-Level Flood Loss Avoidance Results

County	Total Post-2000 Bldg Count	Bldg Count Modeled[1]	Number with Freeboard	SF Modeled (x1,000)	BRV Modeled ($M)	CRV Modeled ($M)	Total Losses Avoided ($1,000)
Alameda	27,582	462	134	4,670	$896	$783	$412
Alpine	191	–	–	–	–	–	–
Amador	3,253	50	–	170	$27	$24	–
Butte	11,814	485	–	1,084	$194	$117	–
Calaveras	5,642	21	–	40	$7	$4	–
Colusa	1,425	68	-	155	$26	$22	–
Contra Costa	49,975	473	226	1,785	$324	$251	$251
Del Norte[2]	0	–	–	–	–	–	–
El Dorado	16,594	30	–	57	$11	$6	–
Fresno	57,055	407	242	1,480	$257	$191	$503
Glenn	1,621	104	–	153	$24	$18	–
Humboldt[2]	0	–	–	–	–	–	–
Imperial[2]	0	–	–	–	–	–	–
Inyo	342	3	–	5	1	$1	–
Kern	63,658	1,247	845	3,552	$599	$492	$1,559
Kings	8,751	114	–	218	$30	$21	–
Lake	4,430	506	471	880	$150	$85	$506
Lassen	1,827	24	–	41	$8	$7	–
Los Angeles	119,134	507	142	3,329	$595	$461	$711
Madera	11,019	523	–	980	$149	$91	–
Marin	4,006	344	72	1,471	$327	$254	$241
Mariposa[2]	0	–	–	–	–	–	–
Mendocino[2]	0	–	–	–	–	–	–
Merced	18,067	2,934	–	4,955	$785	$417	–
Modoc	600	18	–	25	$4	$3	–
Mono	1,076	50	–	75	$11	$5	–
Monterey	11,489	143	134	586	$107	$89	$224
Napa	6,193	133	123	375	$74	$68	$258
Nevada	7,038	22	–	46	$8	$4	$1
Orange	42,142	301	108	759	$141	$71	$155
Placer	49,174	282	136	768	$160	$89	$337
Plumas	1,523	36	–	76	$12	$7	–
Riverside	211,636	3,600	626	7,505	$1,244	$622	$663
Sacramento	83,123	17,145	16,927	49,875	$9,835	$5,759	$30,529
San Benito	1,059	13	–	43	$7	$7	–
San Bernardino	108,298	1,008	37	4,779	$703	$560	$120
San Diego	111,475	1,267	665	3,773	$632	$386	$571
San Francisco	2,476	–	–	–	–	–	–
San Joaquin	52,170	515	508	1,163	$200	$114	$381
San Luis Obispo	17,663	273	51	614	$103	$65	$41
San Mateo	8,511	284	99	1,641	$334	$253	$294
Santa Barbara	10,472	472	129	911	$146	$74	$289

Table 4-4: California County-Level Flood Loss Avoidance Results (cont.)

County	Total Post-2000 Bldg Count	Bldg Count Modeled[1]	Number with Freeboard	SF Modeled (x1,000)	BRV Modeled ($M)	CRV Modeled ($M)	Total Losses Avoided ($1,000)
Santa Clara	36,751	4,870	2,298	19,877	$4,145	$3,513	$6,945
Santa Cruz	5,515	254	133	638	$108	$70	$191
Shasta	10,717	157	28	266	$46	$26	$51
Sierra	316	13	–	21	$4	$2	–
Siskiyou	2,108	59	–	77	$12	$6	–
Solano	20,344	487	205	4,178	$720	$452	$1,017
Sonoma	19,234	239	10	1,304	$237	$182	$87
Stanislaus	32,003	177	38	456	$79	$53	$14
Sutter	6,194	211	41	462	$87	$47	$61
Tehama	5,293	446	4	691	$115	$59	$2
Trinity[2]	0	–	–	–	–	–	–
Tulare	26,698	2,815	–	8,728	$1,478	$972	–
Tuolumne	3,626	7	–	21	$3	$2	–
Ventura	23,131	322	105	1,674	$256	$243	$190
Yolo	12,477	378	200	1,989	$313	$248	$202
Yuba	6,862	312	116	617	$105	$66	$84
Total	**1,343,773**	**44,611**	**24,853**	**139,036**	**$25,836**	**$17,362**	**$46,890**

(1) All buildings with adequate data to model

(2) Not included in the analyses due to incomplete building record data.

BRV = building replacement value; CRV = contents replacement value

Table 4-5: Florida County-Level Flood Loss Avoidance Results

County	Total Post-2000 Bldg Count	Bldg Count Modeled(1)	Number with Freeboard	SF Modeled (x1,000)	BRV Modeled ($M)	CRV Modeled ($M)	Total Losses Avoided ($1,000)
Alachua	17,304	640	612	2,023	$272	$178	$701
Baker	2,453	78	16	134	$15	$10	$8
Bay	21,594	7,246	5,970	13,429	$1,844	$1,080	$2,295
Bradford	1,366	167	3	314	$34	$20	$1
Brevard	50,358	7,647	6,868	22,175	$3,047	$1,658	$6,461
Broward	59,575	56,498	28,057	230,139	$32,160	$20,424	$83,973
Calhoun	802	41	41	58	$6	$4	$22
Charlotte	21,861	11,189	1,975	29,438	$3,406	$1,887	$747
Citrus	17,137	1,366	231	3,229	$363	$225	$102
Clay	25,455	1,761	1,755	4,701	$669	$383	$1,792
Collier	46,837	25,364	2,138	62,128	$8,477	$4,762	$1,267
Columbia	5,085	259	160	473	$50	$32	$28
Desoto	2,189	202	0	348	$38	$28	–
Dixie	1,049	454	4	570	$65	$39	$1
Duval	69,034	2,883	2,125	6,547	$859	$527	$1,130
Escambia	20,826	1,859	341	10,898	$1,599	$844	$480
Flagler	22,984	650	498	1,765	$228	$125	$353
Franklin	1,777	1,315	17	2,935	$341	$185	$9
Gadsden	2,971	58	36	307	$38	$41	$68
Gilchrist	1,837	134	3	204	$22	$13	$1
Glades	893	349	0	566	$59	$47	–
Gulf	2,210	969	792	1,930	$255	$145	$669
Hamilton	829	61	61	113	$12	$8	$19
Hardee	1,587	82	0	165	$17	$15	–
Hendry	2,192	760	165	1,363	$159	$123	$84
Hernando	21,717	595	42	1,195	$144	$78	$13
Highlands	8,708	475	449	923	$98	$60	$555
Hillsborough	107,917	15,367	12,153	49,656	$6,740	$4,249	$3,724
Holmes	1,383	145	133	279	$29	$27	$31
Indian River	20,223	2,729	900	7,781	$1,090	$696	$306
Jackson	3,109	57	54	129	$14	$11	$29
Jefferson	1,292	72	69	165	$17	$15	$27
Lafayette	705	138	138	202	$21	$15	$32
Lake	52,968	1,256	881	2,893	$360	$208	$1,693
Lee	118,239	36,023	2,487	116,209	$15,413	$8,451	$1,326
Leon	16,671	292	114	15,621	$2,435	$1,244	$182
Levy	3,962	484	221	706	$74	$50	$57
Liberty	593	14	13	22	$3	$2	$4
Madison	1,247	86	86	153	$16	$13	$34

Table 4-5: Florida County-Level Flood Loss Avoidance Results (cont.)

County	Total Post-2000 Bldg Count	Bldg Count Modeled[1]	Number with Freeboard	SF Modeled (x1,000)	BRV Modeled ($M)	CRV Modeled ($M)	Total Losses Avoided ($1,000)
Manatee	41,793	5,872	4,610	15,300	$2,108	$1,060	$3,186
Marion	49,519	1,040	362	2,709	$323	$228	$459
Martin	13,381	2,474	1,023	7,881	$1,107	$596	$781
Miami-Dade	67,682	47,546	37,179	190,985	$12,375	$6,187	$15,344
Monroe	5,415	4,567	643	10,067	$1,318	$732	$261
Nassau	11,941	771	765	2,371	$318	$169	$450
Okaloosa	17,553	1,067	866	3,377	$496	$267	$760
Okeechobee	3,307	1,232	12	2,210	$244	$155	$20
Orange	102,633	2,937	2,324	12,076	$1,634	$1,005	$4,544
Osceola	49,027	5,774	5,244	14,603	$1,889	$1,025	$6,678
Palm Beach	82,112	12,782	6,115	47,152	$6,393	$3,982	$7,068
Pasco	63,480	12,116	4,839	31,484	$4,228	$2,431	$4,673
Pinellas	21,929	8,408	1,457	40,939	$5,684	$3,429	$1,565
Polk	70,900	2,686	2,524	5,647	$654	$397	$3,241
Putnam	3,184	395	2	612	$67	$36	$2
St. Johns	47,977	4,443	3,963	18,280	$2,675	$1,754	$4,518
St. Lucie	42,574	1,250	374	3,984	$490	$268	$111
Santa Rosa	24,116	1,533	633	4,165	$596	$307	$693
Sarasota	46,048	6,192	1,853	19,471	$2,719	$1,525	$1,115
Seminole	25,209	1,353	1,271	3,672	$506	$284	$1,411
Sumter	44,718	943	798	2,026	$211	$131	$436
Suwannee	2,941	175	156	262	$28	$18	$34
Taylor	1,181	390	68	785	$83	$54	$61
Union	886	44	1	86	$10	$7	–
Volusia	45,445	2,089	1,427	4,264	$513	$317	$911
Wakulla	4,338	952	14	2,010	$245	$168	$5
Walton	16,618	2,064	2,042	5,415	$752	$422	$2,081
Washington	2,034	103	0	156	$16	$12	–
Total	**1,666,880**	**310,963**	**150,173**	**1,043,872**	**$128,174**	**$74,886**	**$168,634**

(1) All buildings with adequate data to model.

BRV = building replacement value; CRV = contents replacement value

Table 4-6: Selected California and Florida Loss Avoidance Results by Occupancy Groups

State	Occupancy	Total Post-2000 Bldg Count	Bldg Count Modeled*	SF Modeled (x1,000)	BRV Modeled ($M)	CRV Modeled ($M)	Total Losses Avoided ($1,000)
California	Single-Family Dwellings	1,239,763	39,663	81,402	$15,679	$7,840	$35,421
	Multi-Family Dwellings	42,335	1,971	15,038	$3,040	$1,520	$2,805
	Commercial	39,171	1,445	29,290	$4,929	$4,977	$5,925
	Industrial	6,382	477	9,991	$1,677	$2,515	$1,796
	Other	16,150	1,055	3,314	$510	$510	$943
	California Total	**1,343,773**	**44,611**	**139,036**	**$25,836**	**$17,362**	**$46,890**
Florida	Single-Family Dwellings	1,503,290	278,960	657,476	$88,932	$44,466	$147,066
	Multi-Family Dwellings	52,449	14,854	147,929	$18,876	$9,438	$5,687
	Commercial	64,583	10,634	187,290	$14,754	$14,947	$11,430
	Industrial	2,770	353	6,925	$640	$959	$246
	Other	43,792	6,162	44,252	$4,972	$5,077	$4,205
	Florida Total	**1,666,880**	**310,963**	**1,043,872**	**$128,174**	**$74,886**	**$168,634**

The county-level results in Table 4-4 and Table 4-5 show the following variations: the number of buildings that were modeled (total in the floodplain) is close to the number with freeboard, the number of buildings with freeboard is low or zero, and the remainder of the number of buildings with freeboard is in between. It can be inferred from these values that the counties with a nearly equal number of modeled buildings and number with freeboard have long-standing freeboard requirements. A low number or zero with freeboard indicates no freeboard requirement or recently required freeboard requirements. The counties with the number of buildings with freeboard that is between the two extremes indicate some level of freeboard adoption and is most likely for only a portion of the communities in the county in the post-2000 period (2000 to 2018).

The main trends for the AALA values, as expected, are that they are higher in counties with more post-2000 construction and that they are proportional to the number of structures with freeboard value. Counties with more freeboard structures have higher AALA values. A comparison of two counties in a state in which the total AALA is divided by the number with freeboard may indicate which county may have an average higher freeboard value.

Table 4-6 also shows the California and Florida results by occupancy group. Single-family dwellings are subject to the IRC (see Appendix D, Table D.2, for occupancy types and the applicability of IRC or IBC) and represent 91% of the structures that were modeled and 85% of the AALA for the two states. The small difference in the two percentages is because IBC structures (the other occupancies in the table) have larger building areas on average compared to single-family dwellings and have a slightly higher average AALA value per structure.

4.4.2 National Annual Losses Avoided

Table 4-7 summarizes the national flood-related annual losses avoided results.

Table 4-7: Flood Analysis National Annual Losses Avoided

Total Post-2000 Bldg Count	Number in Floodplain	Number with Freeboard	SF Modeled (x1,000)	BRV Modeled ($M)	CRV Modeled ($M)	Total Losses Avoided ($1,000)
17,270,684	**786,473**	**400,498**	**2,496,638**	**$351,351**	**$219,470**	**$483,602**

Of the roughly 786,000 post-2000 structures in the floodplain, about 400,000 or approximately half (51%) had freeboard. The total AALA for the freeboard structures was approximately $484 million or about $1,200 per structure. Building and contents damage contributed to about 56% and 44% of the AALA, respectively. The following sections provide further details on the trends in freeboard adoption and AALA values nationwide.

Top Ten States for Flood AALA

1. Florida .... $169 million
2. Texas .... $63 million
3. California .... $47 million
4. New York .... $24 million
5. New Jersey .... $20 million
6. South Carolina ..... $18 million
7. Arizona .... $18 million
8. Louisiana .... $17 million
9. Indiana .... $16 million
10. North Carolina ..... $10 million

4.4.2.1 Floodplain Analysis and Freeboard Adoption

For all states, about 5% of the structures that were modeled in the study were located in a mapped floodplain. Only 3% of the structures in a mapped floodplain were in Zone V, and the rest were in Zone A floodplains. The FEMA NFHL and associated datasets provided the source data for approximately 75% of the structures in a mapped floodplain; the remaining 25% were from CoreLogic floodplain boundary datasets.

The PELV Curve assignments for Zone A and Zone V are summarized in Table 4-8.

Table 4-8: PELV Curve Percentiles for all Floodplain Structures

Percentile	Zone A	Zone V
Minimum	A1	V1
25th percentile	A4	V9
50th percentile	A6	V12
75th percentile	A10	V17
Maximum	A30	V30

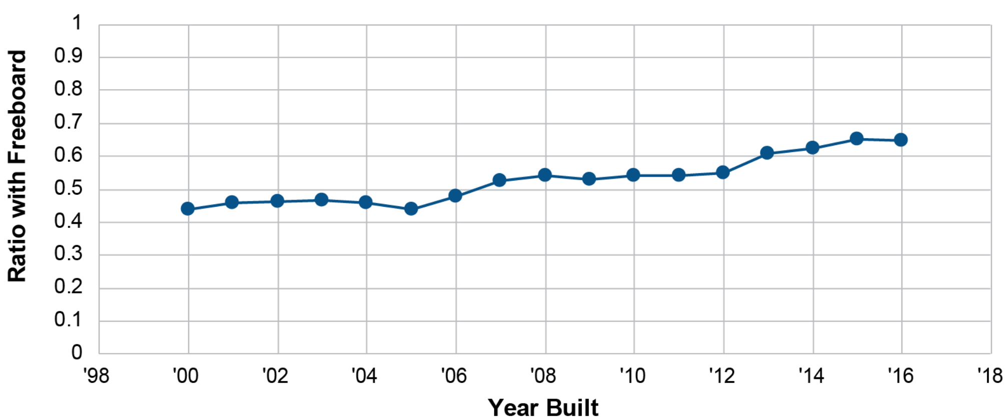
The PELV Curve assignments follow the expected trend of being mostly shallow profiles of Zone A and steeper profiles for Zone V. Spot checks of the assigned PELV Curve values against CoreLogic-based floodplains that retained PELV Curve classifications found good agreement with values, typically within the 25th to 75th percentile interval. Table 4-9 provides the freeboard structure statistics by freeboard adoption category (see Figure 4-4).

Table 4-9: Freeboard Structure Counts by Freeboard Adoption Categories

Category	Floodplain Structures	Freeboard Structures	Percent with Freeboard
Innovator	66,900	63,035	94%
Emergent	485,403	234,900	48%
Limited	234,170	102,563	44%
All States	786,473	400,498	51%

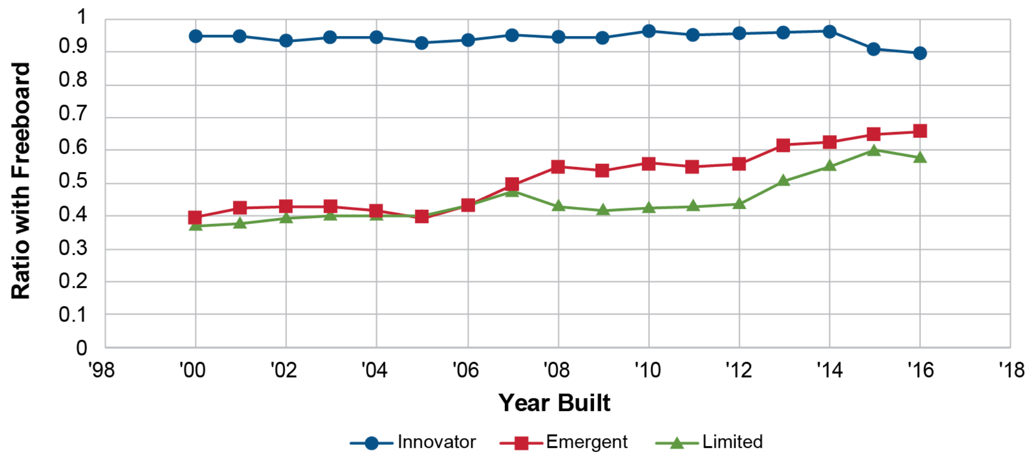
As stated previously, 51% of the floodplain structures were assigned freeboard. Breaking this down into the three freeboard adoption categories, the percentage of states with freeboard follows the expectations: the Innovator states have the highest, followed by Emergent states, and then Limited states. The Emergent states represent a majority of the floodplain structures (62%) and freeboard structures (59%). The Limited states have a higher count of freeboard structures than the Innovator states, most likely caused by larger post-2000 construction.

Figure 4-12 shows the ratio of with-freeboard structures to without-freeboard structures for all states from 2000 to 2016, and Figure 4-13 shows the ratio of with-freeboard structures to without-freeboard structures for the three freeboard adoption categories.



Note: CoreLogic data have incomplete national coverage for 2017 and 2018 and are excluded.

Figure 4-12: Freeboard adoption ratio for all states, 2000 to 2016



Note: CoreLogic data have incomplete national coverage 2017 and 2018 data and were excluded.

Figure 4-13: Freeboard adoption ratio for freeboard adoption categories, 2000 to 2016

Figure 4-12 and Figure 4-13 are based on structure counts with freeboard for year-built data. Figure 4-12 shows a steady increase over time in the ratio with freeboard: from around 0.44 in 2000, to over 0.5 in 2007, and to 0.6 in 2013. The results from 2017 and 2018 were excluded due to incomplete CoreLogic data. A ratio of around 0.80 would be expected based on the freeboard adoption histories for all states.

Figure 4-13 shows how the trend for the Emergent states is a close match to the national trend. The results from 2017 and 2018 were also excluded from this figure. Innovator states almost always have a ratio over 0.9 on average and it would be expected to stay around that value for 2017 and 2018. The Emergent and Limited states have close to the same ratios in 2000 but after 2007, they start to diverge as Emergent states began to adopt statewide freeboard, initially through state-level adoptions. For 2017 and 2018, the Emergent states would be expected to have ratios around 0.90, similar to the Innovator states, due to the mandatory adoption of the IRC and IBC.

Lastly, Table 4-10 shows a breakdown of freeboard levels for all states and for each freeboard adoption category. The average freeboard level is 1.3 feet. The highest percentage for freeboard levels is 1.0 foot and 2.0 feet, making up over 80% of levels overall, and for each freeboard adoption category. The Limited states have a higher percentage with high values (over 39% with 2.0 feet or greater). The Emergent states, while providing a good example with percentage of structures with freeboard as shown previously, have the lowest average freeboard level at 1.2 feet and the highest percentage at the minimum 1.0-foot freeboard in the 2015 and 2018 IRC and IBC.

Table 4-10: Freeboard Level for Freeboard Adoption Categories and All States

Category / All States	0.5 foot (%)	1 foot (%)	1.5 feet (%)	2 feet (%)	2.5 feet (%)	3 feet (%)	4 feet (%)	Average Freeboard Level
Innovator	<1%	52%	14%	30%		4%		1.5 feet
Emergent	10%	69%	1%	17%	<1%	3%	<1%	1.2 feet
Limited	1%	56%	3%	31%		8%	<1%	1.5 feet
All states	**6%**	**63%**	**4%**	**23%**	**<1%**	**4%**	**<1%**	**1.3 feet**

4.4.2.2 Loss Avoidance Values

Table 4-11 provides a state-level summary of the flood analysis results, and Table 4-12 summaries the AALA (i.e., total losses avoided) by freeboard adoption category.

Table 4-11: State-Level Flood Loss Avoidance Results

State	Total Post-2000 Bldg Count	Bldg Count Modeled[1]	Number with Freeboard	SF Modeled (x1,000)	BRV Modeled ($M)	CRV Modeled ($M)	Total Losses Avoided ($1,000)
Alabama	351,452	11,342	3,527	31,556	$4,158	$2,940	$4,498
Alaska	41,288	1,732	48	3,654	$700	$511	$69
Arizona	716,152	11,355	11,350	40,237	$5,731	$4,216	$17,525
Arkansas	199,877	5,305	770	9,816	$1,055	$535	$770
California	1,343,773	44,611	24,853	139,036	$25,836	$17,362	$46,890
Colorado	435,846	3,691	1,607	12,186	$1,616	$1,202	$2,360
Connecticut	84,056	3,120	265	13,496	$2,681	$1,773	$235
Delaware	75,089	4,587	250	9,480	$1,627	$830	$263
District of Columbia	4,762	76	76	965	$159	$99	$190
Florida	1,666,880	310,963	150,173	1,043,872	$128,174	$74,886	$168,634
Georgia	873,229	14,247	4,049	39,477	$5,222	$3,209	$4,130
Hawaii	54,402	1,389	52	4,595	$887	$594	$54
Idaho	178,002	5,153	2,341	13,720	$1,966	$1,232	$2,997
Illinois	260,969	2,998	2,916	7,647	$1,510	$871	$3,896
Indiana	402,869	9,574	9,462	30,249	$4,476	$3,135	$16,315
Iowa	190,078	3,358	3,312	10,796	$1,606	$1,204	$2,879
Kansas	163,850	3,024	2,970	7,468	$993	$743	$2,680
Kentucky	185,879	2,984	233	6,488	$846	$630	$207
Louisiana	96,775	19,517	11,504	67,179	$8,796	$6,348	$17,390
Maine	46,239	1,439	1,439	2,924	$407	$238	$1,735
Maryland	255,607	8,857	6,128	25,819	$3,497	$1,995	$6,100
Massachusetts	149,853	4,738	540	22,584	$4,198	$2,701	$1,004
Michigan	153,472	1,825	1,785	5,342	$773	$450	$2,539
Minnesota	285,818	4,270	4,153	12,583	$2,333	$1,482	$5,350
Mississippi	218,613	17,138	6,793	40,074	$4,882	$3,211	$5,337
Missouri	310,277	5,153	712	17,707	$2,742	$2,003	$665
Montana	102,288	1,818	1,780	4,074	$495	$342	$2,241
Nebraska	124,798	4,342	4,005	16,429	$2,318	$1,703	$3,593
Nevada	344,363	4,037	820	13,182	$1,842	$1,268	$1,544
New Hampshire	71,295	1,910	6	5,773	$892	$600	$6
New Jersey	244,001	36,932	22,476	82,614	$16,382	$9,017	$19,961
New Mexico	105,637	2,283	189	5,671	$699	$485	$247
New York	296,853	12,182	6,281	78,870	$17,045	$9,986	$24,183
North Carolina	870,695	25,902	10,229	69,769	$9,812	$5,620	$9,682
North Dakota	24,891	1,426	1,386	5,403	$888	$553	$1,407
Ohio	513,200	7,488	284	23,772	$3,636	$2,729	$447
Oklahoma	297,439	4,464	696	11,084	$1,271	$1,023	$939
Oregon	249,911	7,605	7,352	16,406	$2,455	$1,596	$5,126
Pennsylvania	387,301	4,766	4,758	22,317	$3,408	$2,984	$5,870
Rhode Island	20,617	1,118	583	2,996	$556	$336	$374
South Carolina	415,687	38,363	20,163	121,207	$19,070	$10,300	$18,082

Table 4-11: State-Level Flood Loss Avoidance Results (cont.)

State	Total Post-2000 Bldg Count	Bldg Count Modeled(1)	Number with Freeboard	SF Modeled (x1,000)	BRV Modeled ($M)	CRV Modeled ($M)	Total Losses Avoided ($1,000)
South Dakota	39,166	686	114	1,777	$250	$179	$62
Tennessee	545,532	8,632	931	26,380	$3,381	$2,414	$987
Texas	2,445,035	95,287	59,035	289,507	$38,395	$25,693	$62,816
Utah	254,486	2,064	64	6,092	$809	$535	$146
Vermont	12,405	286	14	895	$142	$103	$10
Virginia	463,805	8,032	3,748	28,560	$4,239	$2,948	$5,032
Washington	510,178	9,818	3,674	36,060	$5,348	$3,934	$5,448
West Virginia	96,367	3,700	426	6,124	$758	$438	$268
Wisconsin	41,951	167	163	852	$140	$119	$403
Wyoming	47,676	719	13	1,876	$252	$168	$18
Total	**17,270,684**	**786,473**	**400,498**	**2,496,638**	**$351,351**	**$219,470**	**$483,602**

(1) Buildings with adequate data to model

BRV = building replacement value; CRV = contents replacement value

Table 4-12: AALA Summary for Freeboard Adoption Categories and All States

Category / All States	Buildings with Freeboard	AALA (Total Losses Avoided)	Average AALA per Structure
Innovator	63,035	$77,849,643	$1,235
Emergent	234,900	$293,042,678	$1,248
Limited	102,563	$112,709,828	$1,099
All states	**400,498**	**$483,602,149**	**$1,208**

The trends in Table 4-11 are similar to trends for California and Florida (see Section 4.4.1). AALA is proportional to the number of structures with freeboard. States with floodplain structure counts close to the freeboard structure counts have had long-term freeboard adoptions and are in the Innovator freeboard adoption category. States that have adopted statewide freeboard since 2000 are in the Emergent category and have a lower percentage of freeboard structures. States in the Limited category did not have statewide freeboard adoption reflected in the study and tend to have a very low percentage with freeboard. However, there are notable exceptions. Texas has over 50% of its floodplain structures with freeboard, even as a Limited state, and has the second highest state-level AALA value. Texas accounts for over half of the AALA for all Limited states. Louisiana also is a Limited state, with AALA over $10 million, which is surprising because CoreLogic data had availability issues and Louisiana modified the statewide adopted I-Codes to remove freeboard. For both Texas and Louisiana, the higher AALA and freeboard adoption tend to be the result of high levels of post-2000 growth of community-level freeboard requirements, often indicated in the CRS data.

Table 4-12 shows the AALA results summarized by freeboard adoption category. Given all of the variables that could influence the average AALA per structure, including average freeboard levels, relative occupancy composition, and regional replacement value adjustments, it is surprising that all of the category values are within $150 per structure and less than 10% from the average. The most likely reason for Emergent states having slightly greater values than the other states is likely the regional replacement value adjustment because this category includes states such as California and New York.

Table 4-13 summarizes the occupancy structure counts for each freeboard adoption category. Table 4-13 uses Appendix D, Table D-2, to summarize IRC structures (Hazus Occupancies RES1 and RES3A) and IBC structures (all other Hazus occupancies). For all states, the IRC structures represent 86% of floodplain structures. Of the remaining 14% that are IBC structures, a little over half (51%) were assigned freeboard from the various data sources used to develop the freeboard database.

Table 4-13: Structure Counts by I-Code Occupancy Grouping for With and Without Freeboard Structures for Freeboard Adoption Categories and All States

Category / All States	IRC / IBC Structures	With Freeboard Structures	Without Freeboard Structures	Total Floodplain Structures
Innovator	IRC	47,852	3,084	**50,936**
	IBC	15,183	781	**15,964**
Emergent	IRC	210,191	219,057	**429,248**
	IBC	24,709	31,446	**56,155**
Limited	IRC	88,206	111,308	**199,514**
	IBC	14,357	20,299	**34,656**
All States	**IRC**	**346,249**	**333,449**	**679,698**
	IBC	**54,249**	**52,526**	**106,775**

The remaining half of IBC structures (7% of total structures) may have been missed for freeboard assignment. However, in looking at the freeboard adoption category subtotals, the primary potential source of missed IBC structures is in the Emergent states. The Innovator states are already assumed to have statewide freeboard adoptions. The Limited states were the states that were found to not have adopted statewide freeboard during the study period (2000 to 2018). Because most states that use the I-Codes as their basis for statewide freeboard adoption would adopt both the IRC and IBC on a similar schedule, the expectation is that few, if any, Limited states would have adopted the IBC as mandatory without also adopting the IRC as mandatory.

This leaves the Emergent states, which are likely to have adopted IBC editions as mandatory statewide prior to adopting statewide freeboard. The roughly 31,000 IBC structures shown in Table 4-13 for Emergent states represents around 4% of total floodplain structures and likely represents a maximum structure count of the IBC structures that would be assigned a freeboard value if more direct IBC adoption modeling had been used in the study.

The more likely count of missed IBC structures is half of that total, or around 2% of all structures, to take into account the subset of years from 2000 to 2018 when a given state may have had IBC-based freeboard requirements without statewide or IRC-based freeboard requirements. For example, most IBC structures had freeboard requirements added with the 2006 IBC, which was adopted in many states in the 2006 to 2008 period, which would have missed the bulk of the pre-2008 housing construction prior to the Great Recession. Therefore, the original assumption of not separately accounting for the IBC adoptions seem reasonable since the influence on the final results is within 2 to 4%. Higher loss avoidance would have resulted if the additional IBC structures were modeled with freeboard. Additional information on other data quality items can be found in Appendix D, Section D.4.

CHAPTER 5

Hurricane Wind Hazard Analysis

Hurricane wind losses avoided due to the adoption of the I-Codes are presented in this chapter for the 22 states included in the Hazus Hurricane Wind Model (HHWM) plus Washington, DC. Collectively, the states and Washington, DC, are referred to as the hurricane wind hazard study area.[5] Approximately 9.4 million post-2000 buildings, or approximately half of the post-2000 construction inventory nationwide, were constructed in the hurricane wind hazard study area.

The primary challenges in the hurricane wind modeling portion of the BCS Study were:

- Determining code-related wind provisions in each jurisdiction in states where they have not been adopted on a statewide basis.
- Obtaining vulnerability curves that accurately represent the key wind design requirements of the I-Codes, several of which are not reflected in the current Hazus hurricane module (FEMA, 2012e)

The variability of locally adopted wind hazard maps and design provisions means that losses avoided due to the I-Codes can result from (1) an increase in the design hazard level (wind speed) that buildings are required to resist (i.e., hazard zoning maps change over time, most often increasing) or (2) changes to design wind loads or other design provisions (e.g., wind-borne debris protection requirements), given a design wind speed that makes buildings more damage resistant.

The losses from damage in any one hurricane event depend primarily on the wind speeds during the event; nature of the exposed inventory, including the age (age determines which code was used in the design and the resulting building strength); and types of buildings (e.g., occupancy, structural material).

The BCS hurricane wind hazard methodology focused on modeling the losses avoided due to the adoption of I-Code and similar building codes. The main components of the methodology that are described in this chapter are as follows:

[5] The 22 states are Texas, Louisiana, Mississippi, Alabama, Florida, Georgia, South Carolina, North Carolina, West Virginia, Virginia, Maryland, Delaware, Pennsylvania, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, Maine, and Hawaii.

- **Wind code adoption**: Determining which communities had adopted I-Codes (or similar) wind codes.
- **Design wind speed**: Determining the design wind speeds that are applicable to each structure that was constructed pre-I-Codes and to I-Codes.
- **Wind modeling procedure**: Determining how I-Code provisions apply to each structure type and location in order to calculate AALA related to building and contents damage. The AALAs were calculated using an enhanced Hazus wind loss analysis process.

5.1 Wind Code Adoption

The hurricane wind hazard study area included all of the states intersected by the ASCE 7-16 hurricane-prone region (see Figure 5-1), which is everywhere along the Atlantic Ocean and Gulf of Mexico coasts in the U.S. where the basic wind speed for Risk Category II buildings is greater than 115 mph, plus Hawaii. Also, the island territories of Puerto Rico, Guam, the U.S. Virgin Islands, and American Samoa are included in the ASCE 7-16 hurricane region but were excluded from the BCS Study because they are not currently supported in Hazus. Although not in the ASCE hurricane-prone region, the additional HHWM states of West Virginia, Pennsylvania, Vermont, Maine, and Washington, DC, also experience occasional tropical storm activity and may therefore also realize benefits from the I-Codes when subjected to such events.

Figure 3-1 and Figure 3-2 present the IBC and IRC editions, respectively, that are currently (as of April 2020) adopted throughout the country at the statewide level and the states in which adoption is optional at the local level. Proper modeling of the code editions by year requires knowledge of when each code edition was implemented in each jurisdiction; and the assumption, as discussed in Section 2.4.3, of a 1-year lag between the year of code implementation and the year of construction.

The BCS project team investigated the building code wind requirements in the hurricane wind hazard study area and found significant local updates of and amendments to the wind load provisions and wind-borne debris protection requirements in building codes and standards during the study period (2000 to 2018). As discussed in Sections 5.1.2 and Appendix E, Section E.1, the team identified the states in the study area that currently have state-mandated building codes and states that have increased or relaxed hurricane wind provisions in their adopted building codes.

The wind code adoption modeling included determining the basis for the selection of states in the investigation of the history of wind code adoption (Section 5.1.1) and identifying the current wind design requirements in the I-Codes (Section 5.1.2).

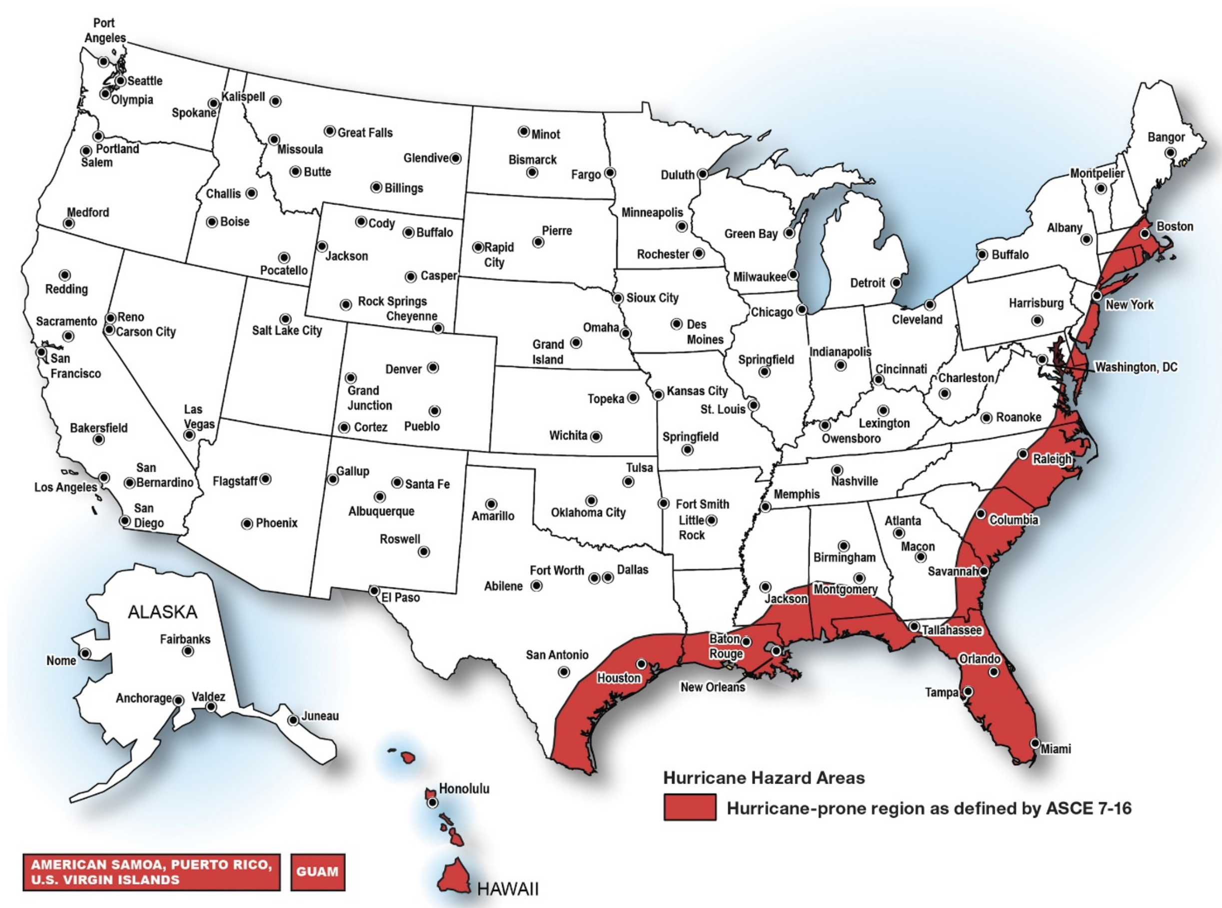


Figure 5-1: Hurricane-prone region as defined by ASCE 7-16 (based on data in ASCE 7-16; used with permission)

Figure 5-1 illustrates the hurricane wind hazard study area, the varying combinations of wind hazard issues or local complexities that were identified, and whether adopted I-Codes are mandated statewide.

5.1.1 Overview of Wind Code Adoption in the Hurricane Wind Hazard Study Area

Conventional construction, which in this context means construction without regard for the effects of hurricanes, was the norm in most hurricane-prone areas for most non-engineered structures until at least the 1990s. In general, the wind load provisions in pre-1980 building codes were simplistic and resulted in wind load design requirements that were far less robust than they are today, particularly for wind uplift. Notable exceptions are:

- South Florida, where greater attention to hurricane vulnerability dates to the initial adoption of the *South Florida Building Code* (SFBC) in Dade County on December 31, 1957 (SFBC, 1957), and soon after that in the unincorporated portions of Broward County.

However, it was not until 1976 that the SFBC was adopted as a mandatory standard for all of Broward County (Broward County, n.d.), and it was not until the mid-1990s that most catastrophic structure failure issues were resolved (Dixon, n.d.).

- Coastal areas of Texas where the Texas Catastrophe Property Insurance Association (TCPIA) promoted voluntary prescriptive construction guidance starting in 1971 for property owners who wanted to obtain insurance through the TCPIA wind pool.
- Coastal areas of North Carolina where the North Carolina State Building Code (NCBCC, 1985) provided additional prescriptive requirements dating to at least the 1980s.

In hurricane-prone coastal areas from Texas to North Carolina, if a building code was enforced locally, the pre-I-Code building code for engineered structures was typically the SBC (SBCCI, 1997), and the general guidance for construction of one- to two-unit dwellings was typically governed by CABO *One- and Two-Family Dwelling Code* (CABO, 1998). Farther north along the hurricane-prone areas adjacent to the Atlantic Ocean coast, where a code was enforced, it was typically the *National Building Code* (BOCA, 1999; Rossberg and Leon, n.d.) for engineered structures and CABO for one- and two-family dwellings. In Hawaii, the UBC (ICBO, 1997) was used for all buildings.

The development and improvement of wind-related building codes and design standards for engineered buildings have steadily improved since the 1960s as research on wind loads and the modeling of hurricane risks have advanced. The most significant changes have been in basic wind speed maps; exposure definitions; component and cladding (C&C) loads that govern the design of the roof and exterior walls, windows, and doors; and the introduction of wind-borne debris protection requirements in the Wind-Borne Debris Region (WBDR).[6]

Post-hurricane damage assessments have clearly shown that structural damage to load-bearing walls and engineered building frames (excluding roof frames and roof-to-wall connections) has been relatively minor in buildings subjected to design-level hurricane wind events if their Main Wind Force Resisting System (MWFRS) did not rely on the integrity of C&C or roof-framing components for some or most of their structural resistance to wind loads. The most common damage in design-level hurricane wind events has been to roof and wall cladding systems, followed by water damage to building interiors and contents due to rainfall infiltration. MWFRS failures have occurred primarily in low-rise commercial buildings where the stability of the MWFRS relied heavily on the integrity of the roof or wall panels (Mehta, 1983; WERC, 1992; Isyumov, 1994; FEMA, 2005).

Outside of the significant strengthening of the SFBC after Hurricane Andrew struck South Florida in 1992 and the changes to the guidance for Texas coastal construction to make it eligible

[6] "ASCE 7-05 defines the windborne debris region as areas within 1 mile of the coastal mean highwater line where the basic wind speed is equal to or greater than 110 mph (and in Hawaii) and in areas where the basic wind speed is equal to or greater than 120 mph (130 mph and 140 mph in ASCE 7-10, respectively)" (FEMA, 2010).

for insurance in the TCPIA wind pool, the most significant change in guidance for hurricane-resistant residential buildings was the development of the SBCCI *Standard for Hurricane Resistant Residential Construction,* SSTD 10-99 (SBCCI, 1999). This standard represented the first comprehensive attempt to apply engineering-based design, with its margins of safety, to the components, connections, and systems that affect the wind resistance of residential buildings. It included guidance for both masonry and wood-frame buildings and spawned the development of material-specific high-wind guides for wood-frame structures and light-gauge steel-frame structures. However, the standard was silent on shingle performance requirements, except to require six nails per shingle. In addition, SSTD 10-99 (SBCCI, 1999) was the first edition of SSTD 10 to have wind-pressure requirements for windows and doors or requirements for protection of glazed openings.

Additionally, the wind provisions in codes from the early 1980s to mid-1990s were not as refined as current wind criteria. As a result, some load conditions of the older codes exceed current criteria, while others fall significantly short of current criteria.

The move to a single national model building code developed by the ICC helped unify the guidance on construction to resist hurricanes; and for the first time outside Florida or the Texas coast, included requirements for protecting glazed openings in the areas subject to the greatest hurricane risks. Initially, the I-Codes (2000 and 2003 editions) had an option for omitting the protection of glazed openings in WBDRs if a building was designed to resist increased internal pressures, but the option was eliminated in the 2006 edition. The 2003 edition introduced requirements for installing shingle roof covers with specific wind ratings.

From a structural design standpoint, the new standards Post-Hurricane Andrew reflect evolutionary improvements over the high wind standards and requirements available in the mid- to late-1990s. Design wind speed maps have evolved as Monte Carlo simulations of hurricane risks have improved. The definitions of wind loads on parapets and overhangs and the differences between C&C loads on hip and gable roofs have also been improved.

Determining which building code was used for a particular building can provide general, but useful, insight about the design loads of the building, but determining how closely the building code was followed is more difficult. For example, the quality of the construction and materials and the degree of building code enforcement may be uncertain. However, quality and enforcement issues are not explicitly addressed in this study.

Although building codes specify design criteria, they also contain conventional and empirical provisions (non-engineered methods based on historical construction methods passed down through generations) for certain building materials, including masonry and wood-framed construction. Limits on the use of conventional and empirical provisions (such as mean roof height, design wind speed/pressure, and seismic shaking levels) have only recently been firmly established (2000 and later editions of IBC and IRC). The conventional and empirical provisions in recent codes are revised to better align with the minimum requirements for engineered methods.

5.1.2 Wind Codes and Standards by Year of Construction

Although the ICC consolidated the three major legacy codes (SBC, BOCA, and UBC) into the model I-Codes that are used today, not every local jurisdiction or state adopts and enforces the same (or any) edition of the model codes. See Section 1.1.3 for a summary of the different ways states and communities adopt building codes.

Table 5-1 summarizes the building codes implemented in the hurricane wind hazard study area as of December 31, 2017, the latest applicable implementation date for the 2000 to 2018 period covered by this study, given the presumed 1-year lag between code implementation and completion of construction. The table also notes amendments made at the state level that strengthen or weaken the hurricane wind hazard-related provisions of the adopted codes.

Code adoption data were collected for 1999 through 2017 for the hurricane wind hazard study area and incorporated into the hurricane wind model. The results are summarized in Table 5-2 for one- and two-family dwellings ("residential") and Table 5-3 for all other buildings ("commercial").

For the states with state-mandated codes, code adoption histories were obtained primarily from the *National Building Code Assessment Report* (ISO, 2015; 2019) supplemented by information obtained from internet searches of state records. In Alabama, Delaware, Georgia, Mississippi, Texas, Vermont (residential only), and West Virginia, adoption and/or enforcement vary by local jurisdiction. For the three counties in Delaware (Kent, Sussex, and New Castle), building code adoption timelines were developed through internet searches. For Mississippi, building code histories were obtained via internet searches but only for the three coastal counties (Jackson, Harrison, and Hancock). For Alabama, Georgia, Texas, Vermont (residential only), and West Virginia, partial building code adoption histories were obtained from a BCEGS database (ISO, 2018a). Although the BCEGS database did not include every community, it enabled modeling of many communities in these five states. Losses avoided were not computed in any jurisdictions where building code histories could not be obtained from one of the above-mentioned sources.

Table 5-1: Building Code Adoption in Hurricane Wind Hazard Study Area as of December 31, 2017

	Codes		
State	**State-Mandated?[(1)]**	**Adopted**	**Amendments to Wind Provisions**
Alabama	No		Adoption varies by local jurisdiction
Connecticut	Yes	IBC/IRC 2012	
Delaware	No	IBC/IRC 2012, 2015	Adoption year varies by county
Florida	Yes	FBC/FBCR 2014	Uses ASCE 7-10 as referenced standard; uses ICC 2012 as code basis with improvements to debris-impact protection
Georgia	Yes	IBC/IRC 2012	Local enforcement is optional
Hawaii	Yes	IBC/IRC 2006	Developed microzoned wind maps that were subsequently adopted into ASCE 7-16
Louisiana	Yes	IBC/IRC 2012	
Maine	No	IBC/IRC 2009	No building code is required in communities with populations of less than 4000
Maryland	Yes	IBC/IRC 2015	Jurisdictions may modify provisions except for wind design requirements
Massachusetts	Yes	IBC/IRC 2009	Specifies design wind speeds for each community
Mississippi	No	IBC/IRC 2009, 2012, or 2015	Jurisdictions were permitted to opt out within 120 days of state adoption
New Hampshire	Yes	IBC/IRC 2009	
New Jersey	Yes	IBC/IRC 2015	
New York	Yes	IBC/IRC 2015	
North Carolina	Yes	IBC/IRC 2009	Reduced area of wind-borne debris requirements
Pennsylvania	Yes	IBC/IRC 2009	
Rhode Island	Yes	IBC/IRC 2012	Reduced area of wind-borne debris requirements
South Carolina	Yes	IBC/IRC 2015	
Texas	No	IBC/IRC 2000, 2003	Adoption varies by local jurisdiction
Vermont	Yes (IBC only)	IBC 2015	Code applies to IBC only; no residential code
Virginia	Yes	IBC/IRC 2012	
West Virginia	No	IBC/IRC 2015	Adoption varies by local jurisdiction
Washington, DC	Yes	IBC/IRC 2012	

(1) A state-mandated code provides a minimum code, which each Authority Having Jurisdiction must adopt and/or enforce.

Table 5-2: Presumed One- and Two-Family Building Codes by Jurisdiction and Year Built

State	County / Parish	Residential Code Adoption Histories by State																			
		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
AL	All	BCEGS State																			
CT	All	CABO							IRC 2003[4]								IRC 2009[4]		IRC 2012[4]		IRC 2015
DC	—	None						IRC 2000									IRC 2012				
DE	Kent	CABO					IRC 2000				IRC 2006						IRC 2012				
	Sussex	CABO						IRC 2003								IRC 2012					
	New Castle	CABO			IRC 2000			IRC 2003		IRC 2006				IRC 2009		IRC 2012			IRC 2015		
FL	All	SBC/SFBC[3]			FBC 2001			FBCR 2004		FBCR 2006		FBCR 2007			FBCR 2010			FBCR 2014			FBCR 2017
GA	All	BCEGS State																			
HI	City / County of Honolulu	UBC								IRC 2003					IRC 2006						
	Hawaii	UBC													IRC 2006						
	Maui	UBC													IRC 2006						
	Kauai	UBC									IRC 2003				IRC 2006						
LA	Jefferson	SBC							IRC 2003					IRC 2009			IRC 2012				
	Orleans	SBC					IRC 2000	IRC 2003						IRC 2009			IRC 2012				
	Plaquemines	SBC							IRC 2003					IRC 2009			IRC 2012				
	Other	None							IRC 2003					IRC 2009			IRC 2012				
MA		CABO									IRC 2003			IRC 2009							IRC 2015
MD	All	CABO			IRC 2000				IRC 2003		IRC 2006		IRC 2009		IRC 2012			IRC 2015			
ME[1]	—	None					IRC 2003						IRC 2009								IRC 2015
MS	Jackson	SBC				IRC 2003														IRC 2012	
	Harrison	CABO						IRC 2003									IRC 2012				
	Hancock	None						IRC 2003													
	Other	None																			
NC	All	CABO		IRC 2000[4]						IRC 2003[4]		IRC 2006[4]		IRC 2009[4]							
NH	All	None			IRC 2000					IRC 2006			IRC 2009								
NJ	All	CABO				IRC 2000				IRC 2006				IRC 2009				IRC 2015			
NY	All	None			IRC 2000						IRC 2003		IRC 2006						IRC 2015		
PA	All	None					IRC 2003						IRC 2009								IRC 2015
RI	All	CABO					IRC 2003[4]			IRC 2006[4]			IRC 2009[4]			IRC 2012[4]					
SC	All	CABO			IRC 2000			IRC 2003				IRC 2006				IRC 2012			IRC 2015		
TX	All	BCEGS State																			
VA	All	CABO				IRC 2000		IRC 2003			IRC 2006			IRC 2009			IRC 2012				IRC 2015
VT	All	BCEGS State																			
WV	All	BCEGS State																			

(1) Building code enforcement only applies to communities with a population of 4,000 or greater
(2) Florida modeled as SBC statewide for the baseline scenario in all losses avoided computations for this study
(3) Miami-Dade and Broward Counties modeled as SFBC; Palm Beach County modeled as SBC plus opening protection requirements statute; remainder of state modeled as SBC
(4) Reduced windborne debris region
BCEGS = Building Code Effectiveness Grading Schedule
CABO = Council of American Building Officials
FBC = Florida Building Code
FBCR = Florida Building Code Residential
IRC = International Residential Code
SBC = Standard Building Code
SFBC = South Florida Building Code
UBC = Uniform Building Code

Table 5-3: Presumed Commercial Building Codes by Jurisdiction and Year Built

State	County / Parish	Commercial Code Adoption Histories by State																			
		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
AL	All	BCEGS State																			
CT	All	BOCA							IBC 2003								IBC 2009[4]		IBC 2012[4]		IBC 2015
DC	—	None						IBC 2000									IBC 2012				
DE	Kent	BOCA					IBC 2000				IBC 2006						IBC 2012				
	Sussex	SBC						IBC 2003								IBC 2012					
	New Castle	BOCA			IBC 2000			IBC 2003		IBC 2006				IBC 2009		IBC 2012			IBC 2015		
FL	All	SBC/SFBC[3]			FBC 2001			FBC 2004		FBC 2006		FBC 2007			FBC 2010			FBC 2014			FBC 2017
GA	All	BCEGS State																			
HI	City / County of Honolulu	UBC								IBC 2003					IBC 2006						
	Hawaii	UBC													IBC 2006						
	Maui	UBC													IBC 2006						
	Kauai	UBC									IBC 2003				IBC 2006						
LA	Jefferson	SBC							IBC 2003					IBC 2009			IBC 2012				
	Orleans	SBC					IBC 2000	IBC 2003						IBC 2009			IBC 2012				
	Plaquemines	SBC							IBC 2003					IBC 2009			IBC 2012				
	Other	None							IBC 2003					IBC 2009			IBC 2012				
MA		BOCA									IBC 2003			IBC 2009							IBC 2015
MD	All	BOCA			IBC 2000				IBC 2003		IBC 2006		IBC 2009		IBC 2012			IBC 2015			
ME[1]	—	None					IBC 2003						IBC 2009								IBC 2015
MS	Jackson	SBC				IBC 2003														IBC 2012	
	Harrison	SBC						IBC 2003									IBC 2012				
	Hancock	None						IBC 2003													
	Other	None																			
NC	All	SBC			IBC 2000[4]				IBC 2003[4]			IBC 2006[4]		IBC 2009[4]							
NH	All	None			IBC 2000					IBC 2006			IBC 2009								
NJ	All	BOCA				IBC 2000				IBC 2006				IBC 2009				IBC 2015			
NY	All	BOCA			IBC 2000						IBC 2003		IBC 2006						IBC 2015		
PA	All	None					IBC 2003						IBC 2009								IBC 2015
RI	All	BOCA					IBC 2003[4]			IBC 2006[4]			IBC 2009[4]			IBC 2012[4]		IBC 2014			
SC	All	SBC		IBC 2000				IBC 2003			IBC 2006					IBC 2012			IBC 2015		
TX	All	BCEGS State																			
VA	All	BOCA				IBC 2000		IBC 2003			IBC 2006			IBC 2009			IBC 2012				IBC 2015
VT	All	BOCA						IBC 2003				IBC 2006			IBC 2012				IBC 2015		
WV	All	BCEGS State																			

(1) Building code enforcement only applies to communities with a population of 4,000 or greater
(2) Florida modeled as SBC statewide for the baseline scenario in all losses avoided computations for this study
(3) Miami-Dade and Broward Counties modeled as SFBC; Palm Beach County modeled as SBC plus opening protection requirements statute; remainder of state modeled as SBC
(4) Reduced windborne debris region
BCEGS = Building Code Effectiveness Grading Schedule
BOCA = Building Officials and Code Administration
FBC = Florida Building Code
IBC = International Building Code
SBC = Standard Building Code
SFBC = South Florida Building Code
UBC = Uniform Building Code

5.2 Wind Hazard Data

One of the most basic ways to compare wind provisions in various editions of the I-Codes is to look at their respective editions of ASCE 7 (the reference standard for determining minimum wind load criteria in the absence of a prescriptive standard). Table 5-4 correlates the building codes considered in this study with the editions of ASCE 7 that they reference. In addition to the design wind speed, design pressures also depend on the enclosure classification (enclosed, partially enclosed, or open), exposure category (general roughness of the surrounding terrain), topography, building height, building geometry, building use, and other site-specific parameters. Furthermore, design wind speeds (referred to in ASCE 7-98 and subsequent editions as basic wind speeds) cannot be directly compared across editions of ASCE 7 without first accounting for differences in wind speed averaging times (i.e., fastest mile versus peak 3-second gust) and mean recurrence intervals (i.e., return periods).

Table 5-4: Correlation between Model Building Codes and Referenced Editions of ASCE 7

Model Commercial Code	ASCE 7 Edition	Model Residential Code	ASCE 7 Edition
SBC(1)	—	CABO(1)	—
BOCA(1)	—	—	—
UBC(1)	—	—	—
2000 IBC	ASCE 7-98	2000 IRC	ASCE 7-98
2003 IBC	ASCE 7-02	2003 IRC	ASCE 7-02
2006 IBC	ASCE 7-05	2006 IRC	ASCE 7-05
2009 IBC	ASCE 7-05	2009 IRC	ASCE 7-05
2012 IBC	ASCE 7-10	2012 IRC	ASCE 7-10(2)
2015 IBC	ASCE 7-10	2015 IRC	ASCE 7-10
2018 IBC	ASCE 7-16	2018 IRC	ASCE 7-16(3)

(1) SBC, BOCA, UBC, and CABO used the same wind speed map as ASCE 7-93.

(2) Prescriptive wind pressures were still based on ASCE 7-05. The simplified wind pressure table and wind speed maps were based on ASCE 7-10 but were converted to allowable stress design.

(3) Prescriptive wind pressures were still based on ASCE 7-10. The simplified tables were based on ASCE 7-10, but in regions where wind design is required, ASCE 7-16 applies.

Figure 5-2, Figure 5-3, and Figure 5-4 provide a comparison of ASCE 7-93, ASCE 7-98, and ASCE 7-10 wind speed maps, respectively. The change in the unit of measurement and return period should be noted: fastest mile wind speed corresponding to a 50-year mean recurrence interval (MRI) (ASCE 7-93); 3-second gust corresponding to a 700-year MRI ultimate design wind speed divided by the square root of the wind load factor, generally resulting in MRIs between 50 and 100 years (ASCE 7-98); and 3-second gust wind speed corresponding to a 700-year MRI ultimate design wind speed (ASCE 7-10). Note in the 2012 IBC, 2015 IRC, and

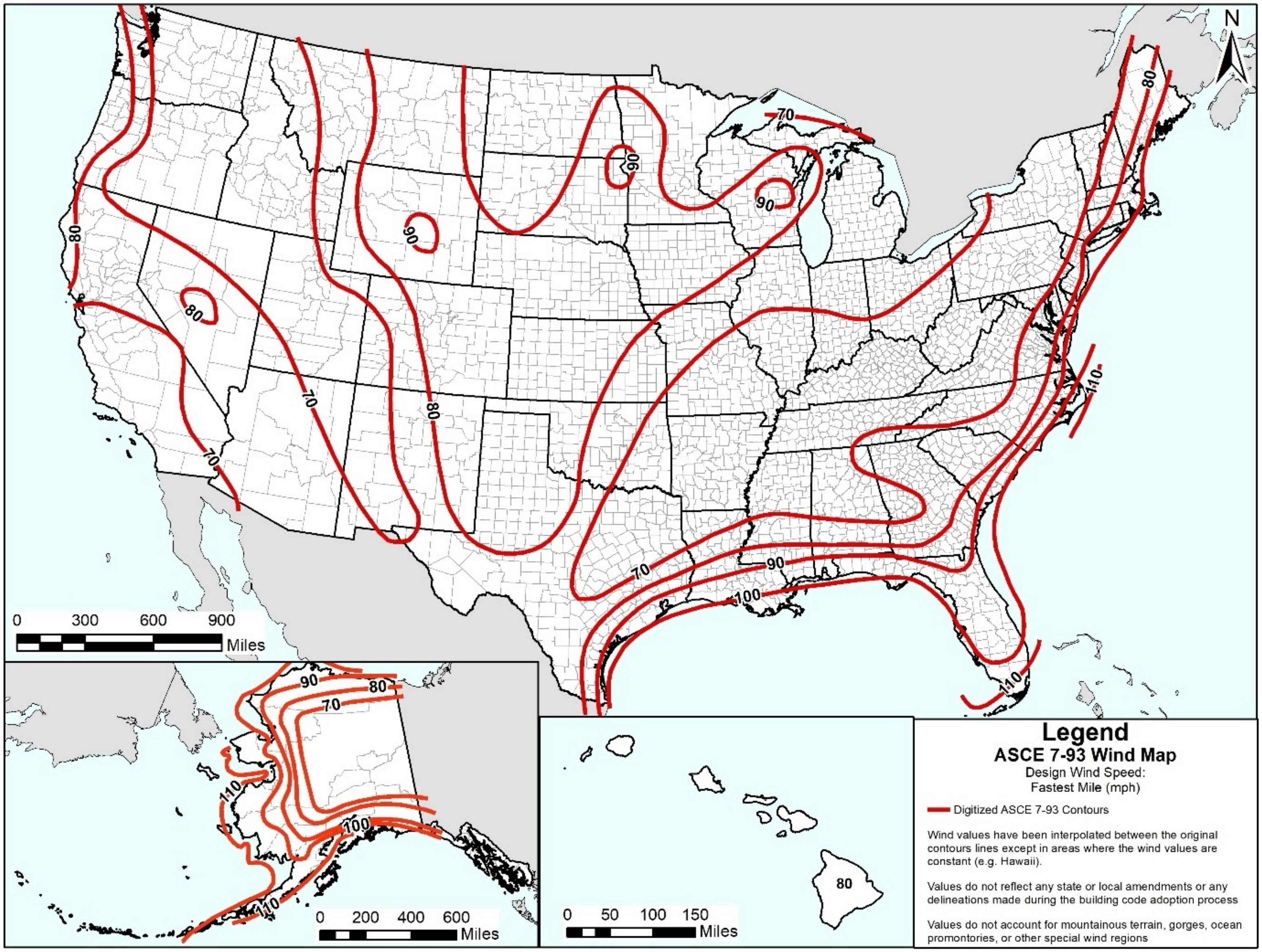


Figure 5-2: Basic wind speed map in ASCE 7-93 (adapted from ASCE 7-93 with permission)

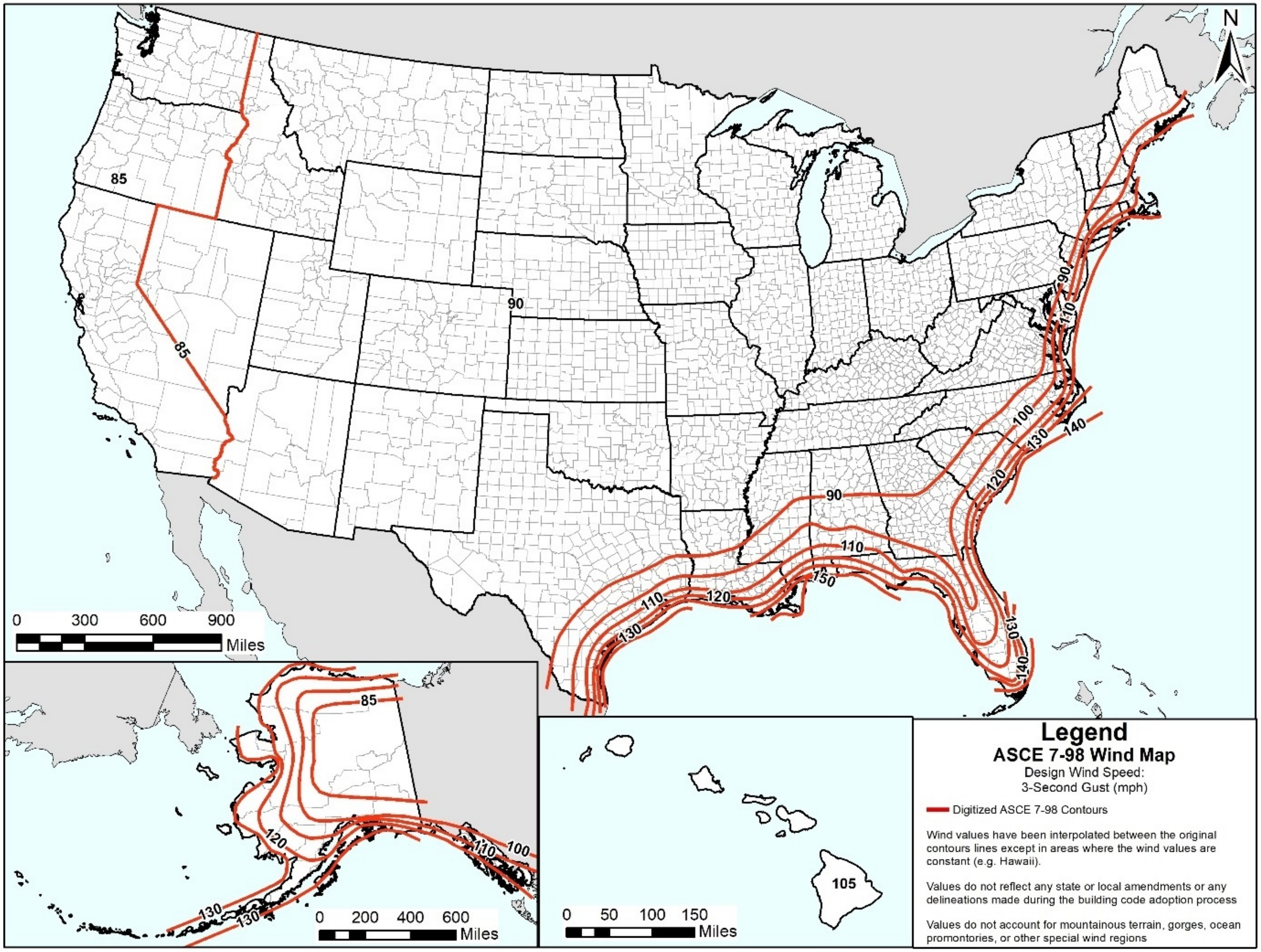


Figure 5-3: Basic wind speed map in ASCE 7-98 (adapted from ASCE 7-98 with permission)

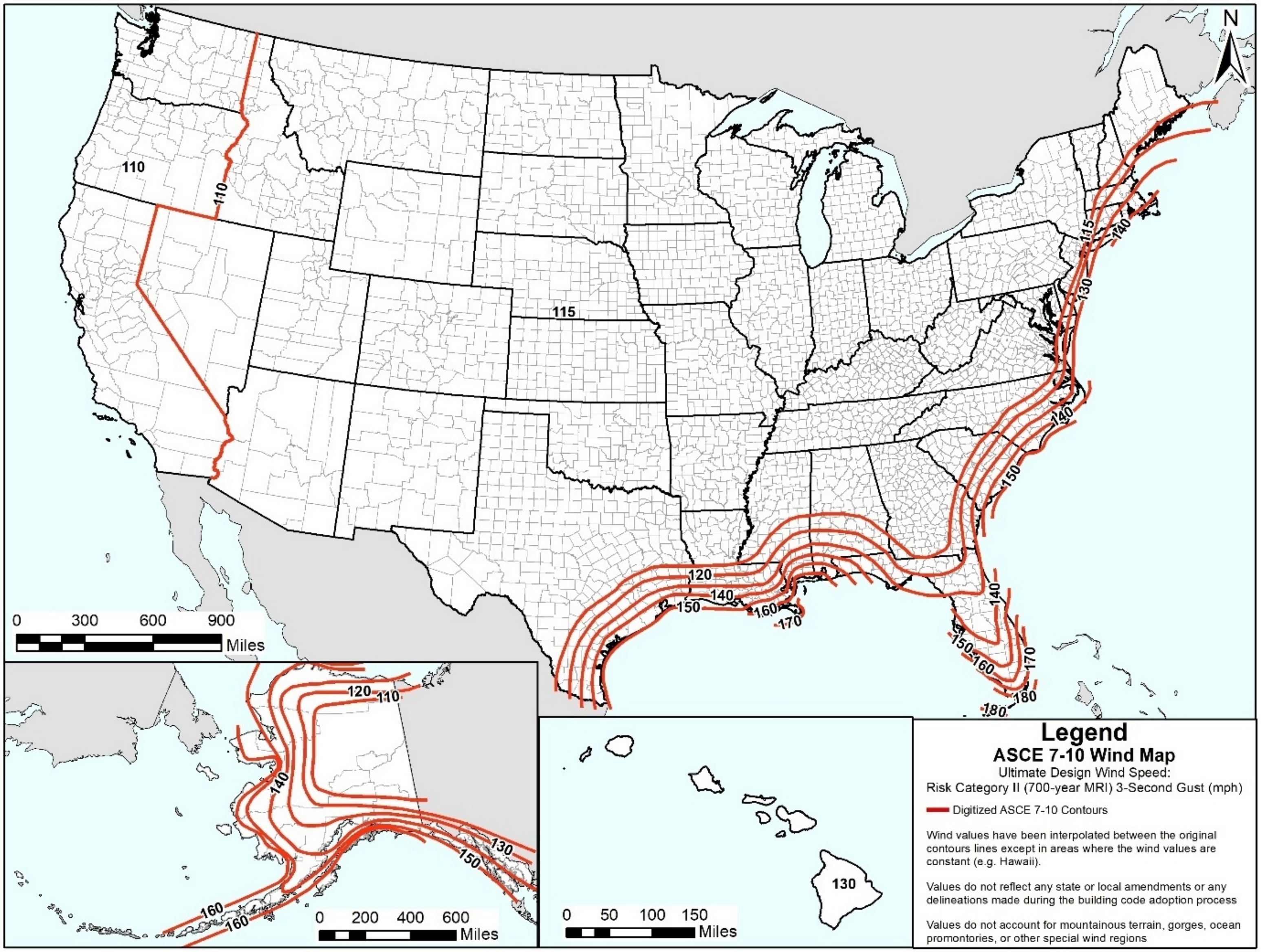


Figure 5-4: Basic wind speed map in ASCE 7-10 (adapted from ASCE 7-10 with permission)

subsequent editions, the latter is referred to as the "ultimate design wind speed." In addition to the changes in wind speed averaging time and MRI, the hurricane wind speed contours in ASCE 7 have evolved over time due to advancements in hurricane hazard modeling. In ASCE 7-98, the hurricane wind hazard contours were updated based on the work of Vickery et al. (2000a; 2000b); and in ASCE 7-10, the hurricane wind hazard contours were updated again based on the work of Vickery et al. (2009a; 2009b).

In general, the largest changes to resulting loads from wind speeds in the hurricane-prone areas occurred between ASCE 7-05 and ASCE 7-10 and again between ASCE 7-10 and ASCE 7-16. ASCE 7-10 loads were significantly reduced relative to ASCE 7-05 loads for both MWFRS and C&C loads, except along the coastline where terrain Exposure D was reintroduced in hurricane-prone regions. The reductions were due to the adoption of maps with what turned out to be effectively lower hurricane design wind speeds for the same return periods. A change that effectively reduced or eliminated the ASCE 7-10 reductions in C&C loads occurred in ASCE 7-16, due primarily to improvements in roof C&C pressure coefficients for buildings with flat, gabled, and hipped roofs and mean roof heights less than or equal to 60 feet. In addition to new log graphs and zones, the net effect is increased wind pressures for most of the described roof configurations. In some cases, the increases are significant (more than doubled) over ASCE 7-10 C&C design loads but resulted in less of an increase when compared to ASCE 7-05 C&C design loads. However, due to the changes in the hurricane simulation modeling, MWFRS wind loads, and wall C&C design pressures—which include window and door design pressures—in hurricane-prone regions are reduced in both ASCE 7-10 and ASCE 7-16 versus loads provided by ASCE 7-98 through ASCE 7-05.

5.3 Wind Modeling Methodology

Annual losses avoided were calculated in the nationwide study as the differences between the pre-I-Code scenario and the I-Code or similar code scenario. The pre-I-Codes are BOCA, CABO, SBC, and UBC (Hawaii) (see Table 5-2 and Table 5-3). The actual code in place at the time of construction depends on the building's location and year built. When the actual code is an I-Code or similar code, there is frequently a reduction in the expected AAL compared to the pre-I-Code AAL, resulting in losses avoided.

Figure 5-5 provides an overview of the hurricane wind analysis methodology. The CoreLogic post-2000 building inventory data were supplemented by updated Hazus Replacement Cost Models and the building code history information described in Sections 5.1 and 5.2 and Appendix E, E.1, to generate the required inputs for each building. The hurricane wind loss computations are depicted within the dotted rectangle. As described in Appendix E, Section E.2, several enhancements to the existing Hazus hurricane wind loss methodology were developed and implemented to capture the key benefits of the I-Codes or similar codes.

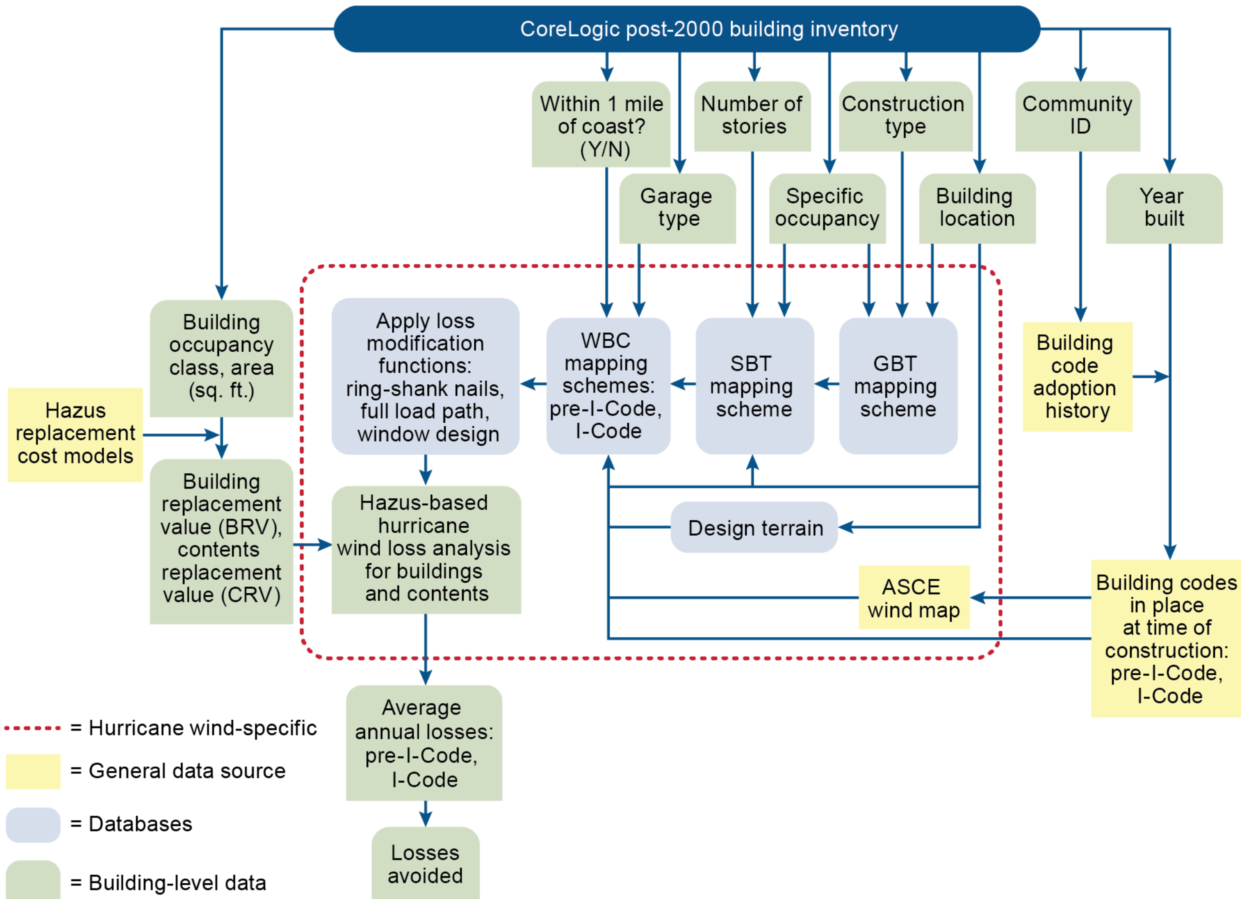


Figure 5-5: Hurricane wind methodology

Building characteristics not explicitly provided in the parcel data were modeled based on the building location and year of construction. Building characteristics affecting expected losses include but are not limited to:

- Location/exposure
- Number of stories
- Roof shape
- Roof slope
- Roof cover material
- Roof cover strength
- Roof deck material
- Roof deck attachment
- Secondary water resistance
- Roof-to-wall connection

- Window design pressure
- Opening protection
- Wall construction
- Soffit construction

Some of the above characteristics are affected by the wind-loading provisions of the building codes considered in this study but are not limited by them; specifically, location/exposure, number of stories, roof shape, roof slope, roof cover material, roof deck material, type of wall construction, and soffit construction. The characteristics in the above list that have been addressed by changes in building code provisions are: roof cover strength, roof deck attachment, roof-to-wall connections, window design pressure, and opening protection. As discussed in Appendix E, Section E.2, some of the characteristics are addressed in the existing Hazus model, some have been addressed by modifying existing Hazus model fragility curves for related characteristics, and some will need to be addressed in a future effort.

As discussed in Appendix E, Section E.2, some of the characteristics have been addressed in the existing Hazus model, some have been addressed by modifying existing Hazus model fragility curves for related characteristics, and some will need to be addressed in a future effort.

The building characteristics of primary concern are:

- Opening protection (shutters or impact-resistant glazing)
- Continuous load path (represented in Hazus by roof-to-wall connection characteristics)
- Roof deck attachment
- Roof cover strength (represented for residential buildings by a modification to the Hazus vulnerability curves for buildings with secondary water resistance)
- Reinforcement in masonry wall systems

The building characteristics listed below are a matter of architectural preference, material preference, or siting conditions and were not considered as potential sources of avoided losses.

- General building type (wood, masonry, reinforced concrete, or steel)
- Roof shape (hip, gable, or flat)
- Roof covering material (shingles, tile, metal, built-up, or single-ply membrane)
- Local surface roughness (z_0)
- Types of surrounding buildings that may be potential sources of wind-borne debris (residential or commercial)

Although the five characteristics listed above affect the expected damage as a function of wind speed, they are not determined by the adoption of a building code. For parcels with insufficient data on building characteristics that are not directly influenced by building codes (e.g., roof shape), the presumed distributions are based on the existing HHWM default assumptions.

Code requirements for characteristics, such as opening protection, that are effective only in WBDRs were modeled based on the location of the building with respect to the WBDR and the requirements in effect in the WBDR at the time of construction.

Therefore, the final distribution of wind building characteristics used for each building depends on inputs derived from the parcel data described in Chapter 3, year of construction, applicable building code, design wind speed, distance from the coast, and other factors. For example, 100% of the one- and two-family dwellings located in the WBDR are assumed to have shutters (or other equivalent opening protection) under the 2007 and later editions of the *Florida Building Code, Residential* (FBCR) or the 2006 and later editions of the IRC.

The parcel-level data described in Chapter 3 were augmented with appropriate code-based building characteristics based on the parcel location and year of construction. The existing HHWM Specific Building Type (SBT) mapping schemes that relate General Building Type (GBT) and Specific Occupancy to SBT were used as the starting point and then adjusted where the parcel data provided definitive characteristics. In Florida, the most frequently available characteristics were number of stories and GBT. Other less frequently available characteristics included garage (attached/detached/none), roof cover, and roof shape.

For the purposes of this study, the existing default HHWM Wind Building Characteristics (WBCs) were also modified based on the following building code provisions:

- Applicable building code
- Occupancy
- Height (inferred from number of stories)
- Design wind speed
- Design exposure
- WBDR design option:
  - No WBDR defined
  - Partially enclosed design permitted in the WBDR
  - Enclosed design with opening protection required in the WBDR

Although the addition of shutters (or equivalent levels of opening protection) provides one of the largest benefits in the Hazus model analysis for many building types, the early editions of the I-Codes and similar codes allowed the option to forego opening protection if the building was designed to withstand higher internal pressures. The choices made for particular buildings generally cannot be determined from available databases. Consequently, the study relied on the existing Hazus defaults and engineering judgment to estimate the percentage of buildings built during various periods with the various options. In addition, Hazus does not separately address the use of wood structural panels, which are permitted in many cases as an alternative to products that meet ASTM International (ASTM) E1886 (ASTM, 2013) and ASTM E1996 (ASTM, 2014) standards.

The HHWM models the general building stock on an aggregate rather than individual basis. To address this limitation, a new Stand-alone Hazus Hurricane Wind Model (SHHWM) was developed for the study to compute AALs and losses avoided on a building-by-building basis. In addition, to address key modeling limitations of the current HHWM, three new sets of Loss Modification Functions (LMFs) were developed and implemented in the SHHWM. The details of the SHHWM and examples of the newly developed LMFs are presented in Appendix E.

5.4 Hurricane Wind Modeling Results

In this section, the hurricane wind losses avoided results are presented, first for the state of Florida and then for the hurricane wind hazard study area. The Florida results are presented first because Florida accounts for 81% of the national total for hurricane wind losses avoided and the Florida results illustrate many of the key issues and findings of the hurricane wind losses avoided study. The national results are presented in tabular form by state and in a series of county-level maps. A link to all of the data underlying the county maps is provided in Appendix A, Section A.2.

5.4.1 Florida Average Annual Losses Avoided

This section summarizes the key attributes of the post-2000 Florida building inventory and presents the AALA due to the adoption of the FBC.

5.4.1.1 Post-2000 Florida Building Replacement Value

An estimate of the post-2000 Florida building inventory was generated using the methodology described in Chapter 3. The results are summarized in the tables below. Table 5-5 presents the building count, BRV, contents replacement value (CRV), and total (buildings plus contents) replacement value (TRV). All replacement values were estimated using previously developed Hazus methodologies. Table 5-5 also includes the building counts and TRVs as percentages of their respective totals. It can be seen that a majority of the post-2000 Florida building inventory was completed between 2000 and 2008 (76% by count; 73% by TRV).

Table 5-6 summarizes the post-2000 Florida inventory by construction type. A key takeaway from Table 5-6 is that approximately 70% of the inventory (either by building count or TRV) is of unknown construction type. Fortunately, construction type is, in general, of secondary importance to other wind design attributes, such as number of stories, roof-to-wall connection, roof deck attachment, and protection of glazed openings. Nonetheless, the widespread lack of

Table 5-5: Post-2000 Florida Building Inventory by Year Built

Year Built	Building Code Residential	Building Code Commercial	Count	BRV ($M)	CRV ($M)	TRV ($M)	Count (%)	TRV (%)
2000	SBC/SFBC[1]	SBC/SFBC[1]	124,470	$50,859	$33,403	$84,263	7.5%	7.9%
2001	SBC/SFBC[1]	SBC/SFBC[1]	127,010	$49,309	$30,096	$79,405	7.6%	7.5%
2002	SBC/SFBC[1]	SBC/SFBC[1]	133,774	$49,274	$29,817	$79,091	8.0%	7.4%
2003	FBC 2001	FBC 2001	150,362	$53,929	$32,341	$86,271	9.0%	8.1%
2004	FBC 2001	FBC 2001	167,039	$58,761	$34,422	$93,183	10.0%	8.8%
2005	FBC 2001	FBC 2001	188,154	$65,478	$37,352	$102,830	11.3%	9.7%
2006	FBCR 2004	FBC 2004	194,876	$71,907	$41,729	$113,636	11.7%	10.7%
2007	FBCR 2004	FBC 2004	116,789	$51,162	$32,643	$83,806	7.0%	7.9%
2008	FBCR 2006[2]	FBC 2006[3]	60,376	$30,357	$20,945	$51,302	3.6%	4.8%
2009	FBCR 2006[2]	FBC 2006[3]	36,562	$20,016	$13,729	$33,746	2.2%	3.2%
2010	FBCR 2007	FBC 2007	33,861	$15,583	$10,219	$25,802	2.0%	2.4%
2011	FBCR 2007	FBC 2007	31,384	$13,246	$8,358	$21,604	1.9%	2.0%
2012	FBCR 2007	FBC 2007	37,579	$16,820	$10,810	$27,630	2.3%	2.6%
2013	FBCR 2010	FBC 2010	51,853	$21,653	$12,623	$34,276	3.1%	3.2%
2014	FBCR 2010	FBC 2010	57,510	$25,584	$15,229	$40,813	3.5%	3.8%
2015	FBCR 2010	FBC 2010	63,254	$26,646	$15,728	$42,374	3.8%	4.0%
2016	FBCR 2014	FBC 2014	71,140	$31,065	$18,274	$49,340	4.3%	4.6%
2017[4]	FBCR 2014	FBC 2014	19,664	$8,735	$5,361	$14,096	1.2%	1.3%
2018[4]	FBCR 2014	FBC 2014	691	$197	$108	$305	0.0%	0.0%
		Total	**1,666,348**	**$660,583**	**$403,189**	**$1,063,772**	**100.0%**	**100.0%**

(1) Miami-Dade and Broward Counties modeled as SFBC; Palm Beach County modeled as SBC plus opening protection requirements statute; remainder of state modeled as SBC.

(2) FBCR 2006 is an unofficial designation used herein for the FBCR 2004 with 2006 and 2007 supplements.

(3) FBC 2006 is an unofficial designation used herein for the FBC 2004 with 2006 and 2007 supplements.

(4) Incomplete data.

Table 5-6: Post-2000 Florida Building Inventory by Construction Type

Hazus General Building Type	Count	BRV ($M)	CRV ($1M)	TRV ($1M)	Count (%)	TRV (%)
Masonry	368,836	$143,627	$87,842	$231,468	22.1%	21.8%
Wood Frame	25,098	$8,907	$5,257	$14,164	1.5%	1.3%
Concrete	60,175	$40,466	$27,186	$67,652	3.6%	6.4%
Steel	10,629	$11,711	$11,887	$23,598	0.6%	2.2%
Unknown	1,201,610	$455,872	$271,018	$726,890	72.1%	68.3%
Total	**1,666,348**	**$660,583**	**$403,189**	**$1,063,772**	**100.0%**	**100.0%**

data on construction type does illustrate the benefits of carrying forward the existing HHWM mapping schemes into the SHHWM methodology to deal with unknowns in a rational and unbiased manner.

5.4.1.2 Florida Losses Avoided

The Florida results are summarized in Table 5-7 through Table 5-10. As shown in Table 5-7, the Florida counties with the largest AALAs are three densely populated counties in southeastern Florida: Miami-Dade, Broward, and Palm Beach. Together, the three counties account for 53% of the statewide AALA. Their large contribution is due to their early adoption of modern wind design criteria, high hazard levels, and high rates of new construction since 2000 (20% of the statewide post-2000 BRV.

Table 5-7: Average Annual Losses Avoided by County in Florida

County	Total Post-2000 Bldg Count	Bldg Count Modeled[(1)]	SF Modeled (x1,000)	BRV Modeled ($M)	CRV Modeled ($M)	Total LA ($1,000)
Alachua	17,304	17,304	52,627	$6,844	$4,355	–$35
Baker	2,453	2,452	4,326	$508	$323	$0
Bay	21,594	21,594	54,003	$7,109	$4,369	$6,151
Bradford	1,366	1,366	2,647	$296	$200	$0
Brevard	50,358	50,356	134,647	$17,853	$10,179	$12,571
Broward	59,575	59,575	265,353	$36,554	$23,423	$154,121
Calhoun	802	802	1,290	$136	$105	$7
Charlotte	21,861	21,859	55,608	$6,808	$3,887	$6,747
Citrus	17,137	17,137	36,284	$4,157	$2,337	$397
Clay	25,455	25,455	63,066	$8,839	$4,983	–$272
Collier	46,837	46,837	113,849	$15,487	$8,641	$30,096
Columbia	5,085	5,085	11,654	$1,285	$910	$63
DeSoto	2,189	2,189	5,077	$562	$448	$152
Dixie	1,049	1,049	1,610	$184	$137	$14
Duval	69,034	69,034	226,356	$29,481	$18,262	$3,036
Escambia	20,826	20,824	58,483	$7,874	$4,798	$12,332
Flagler	22,984	22,984	53,845	$6,786	$3,817	$1,582
Franklin	1,777	1,777	3,993	$465	$262	$75
Gadsden	2,971	2,971	6,214	$690	$490	$7
Gilchrist	1,837	1,837	2,925	$319	$238	$8
Glades	893	893	1,342	$141	$110	$62
Gulf	2,210	2,210	4,774	$613	$379	$157
Hamilton	829	829	1,466	$163	$129	$4
Hardee	1,587	1,587	3,267	$369	$312	$108
Hendry	2,192	2,192	3,778	$430	$315	$192
Hernando	21,717	21,717	45,501	$5,485	$3,112	$349
Highlands	8,708	8,708	17,468	$1,955	$1,253	$314
Hillsborough	107,917	107,917	348,524	$48,744	$30,263	$26,576
Holmes	1,383	1,383	2,342	$257	$224	$20
Indian River	20,223	20,223	51,720	$6,995	$4,058	$11,488
Jackson	3,109	3,109	7,109	$799	$625	$31
Jefferson	1,292	1,292	2,481	$267	$190	$4
Lafayette	705	705	1,021	$113	$88	$2
Lake	52,968	52,968	120,457	$15,344	$8,834	$1,626
Lee	118,239	118,234	325,653	$42,266	$24,064	$47,961
Leon	16,671	16,545	100,986	$13,298	$10,600	$88
Levy	3,962	3,962	5,807	$622	$449	$38
Liberty	593	593	994	$115	$94	$4
Madison	1,247	1,247	2,894	$335	$344	$15

Table 5-7: Average Annual Losses Avoided by County in Florida (cont.)

County	Total Post-2000 Bldg Count	Bldg Count Modeled[(1)]	SF Modeled (x1,000)	BRV Modeled ($M)	CRV Modeled ($M)	Total LA ($1,000)
Manatee	41,793	41,791	96,653	$13,831	$6,945	$13,711
Marion	49,519	49,519	107,596	$12,647	$7,594	$365
Martin	13,381	13,373	39,639	$5,323	$3,066	$14,332
Miami-Dade	67,682	67,681	355,953	$48,799	$34,314	$267,381
Monroe	5,415	5,415	11,712	$1,528	$872	$2,506
Nassau	11,941	11,928	30,911	$4,023	$2,236	$420
Okaloosa	17,553	17,552	46,087	$6,279	$3,613	$5,343
Okeechobee	3,307	3,307	6,141	$694	$478	$195
Orange	102,633	102,631	406,044	$55,842	$34,283	–$4,903
Osceola	49,027	49,025	146,730	$19,086	$10,775	–$1,601
Palm Beach	82,112	82,112	308,213	$43,993	$26,556	$171,197
Pasco	63,480	63,480	148,940	$20,269	$11,453	$2,875
Pinellas	21,929	21,570	109,223	$14,957	$10,135	$11,127
Polk	70,900	70,900	172,975	$20,463	$12,628	$2,796
Putnam	3,184	3,184	5,503	$629	$407	–$10
St. Johns	47,977	47,977	156,841	$22,278	$13,645	$4,205
St. Lucie	42,574	42,569	104,416	$12,785	$7,358	$15,735
Santa Rosa	24,116	24,115	55,770	$7,472	$4,272	$9,081
Sarasota	46,048	46,048	118,264	$15,899	$9,789	$16,509
Seminole	25,209	25,209	92,508	$13,168	$7,823	–$671
Sumter	44,718	44,718	88,296	$9,953	$5,516	$1,387
Suwannee	2,941	2,941	4,208	$461	$334	$19
Taylor	1,181	1,181	2,311	$262	$199	$9
Union	886	886	1,666	$184	$141	$2
Volusia	45,445	45,445	96,259	$12,214	$7,076	$2,425
Wakulla	4,338	4,338	7,949	$989	$593	$37
Walton	16,618	16,618	40,770	$5,612	$3,186	$6,231
Washington	2,034	2,034	3,610	$393	$294	$28
Total	**1,666,880**	**1,666,348**	**4,966,628**	**$660,583**	**$403,189**	**$856,824**

(1) All buildings with adequate data to model.

The total AALs (building plus contents) for the post-2000 Florida building inventory are given in Table 5-8. The AALTnew column shows the AAL using the "new" I-Code (or similar code) provisions, and the AALTold column shows the AAL pre-I-Code assuming that SBC 1997 (SBCCI, 1997) provisions were in effect statewide from 2000 to 2018. The losses avoided column shows the total annual losses avoided (i.e., AALTold minus AALTnew). The results are divided into three groups: buildings with positive losses avoided (benefits), buildings with zero losses avoided (no change from baseline), and buildings with negative losses avoided (costs). Instances of negative losses avoided occur primarily in inland areas of Central Florida where the shapes and spacing of the contours on the basic wind speed maps changed the most from ASCE 7-93 to ASCE 7-98. Additional details on the causes of the negative losses avoided are provided in Section 5.4.2. Although the negative losses avoided group includes 13% of the locations, these locations account for just 5% of the pre-I-Code AAL and only 3% of the total losses avoided.

Table 5-8: Florida Average Annual Losses and Losses Avoided

Losses Avoided Group	Count	Count (%)	AALTnew ($1,000)	AALTold ($1,000)	AALA ($1,000)
Positive	907,321	54.4%	$1,068,065	$1,950,944	$882,879
No Change	538,705	32.3%	$437,757	$437,757	–
Negative	220,322	13.2%	$141,140	$115,084	$–26,056
Total	**1,666,348**	**100.0%**	**$1,646,961**	**$2,503,785**	**$856,824**

Table 5-9 summarizes the losses avoided by building code edition and whether buildings are inside the High-Velocity Hurricane Zone (HVHZ) or WBDR. From the results, it is clear that the location of the building with respect to the WBDR or HVHZ is the dominant factor in determining losses avoided. Over 95% of the losses avoided come from the 40% of the post-2000 buildings that are in the HVHZ or WBDR. Conversely, approximately 20% of the buildings were modeled as being constructed in 2000, 2001, or 2002 under the SBC, resulting in only limited losses avoided. The SBC did not have a WBDR or opening protection requirements. The only exception is Palm Beach County, which had a local ordinance that required opening protection for several occupancy types, including single-family dwellings. Table 5-9 also shows the average loss avoided per building.

Note the significant increase in average loss avoided under the FBC 2006 when the option to omit opening protection in the WBDR and the Panhandle Exception to the WBDR were removed.

Table 5-9: Florida Average Annual Losses Avoided by Florida Building Code Edition

Design Code	Inside WBDR or HVHZ?	Count	LA ($1,000)	Count (%)	LA (%)	Average AALA ($)
FBC 2014	Y	53,467	$99,443	3.2%	11.6%	$1,860
FBC 2010	Y	94,152	$171,705	5.7%	20.0%	$1,824
FBC 2007	Y	48,363	$96,776	2.9%	11.3%	$2,001
FBC 2006(1)	Y	42,032	$105,678	2.5%	12.3%	$2,514
FBC 2004	Y	143,752	$99,454	8.6%	11.6%	$692
FBC 2001; SFBC 1994	Y	289,055	$244,196	17.3%	28.5%	$845
FBC 2014	N	38,028	$4,209	2.3%	0.5%	$111
FBC 2010	N	78,465	$8,883	4.7%	1.0%	$113
FBC 2007	N	54,461	$7,292	3.3%	0.9%	$134
FBC 2006(1)	N	54,906	$6,225	3.3%	0.7%	$113
FBC 2004	N	167,913	–$6,968	10.1%	–0.8%	–$41
FBC 2001	N	258,496	–$15,480	15.5%	–1.8%	–$60
SBC 1997	N	343,258	$35,411	20.6%	4.1%	$103
Subtotal	Y	670,821	$817,251	40.3%	95.4%	$1,218
Subtotal	N	995,527	$39,572	59.7%	4.6%	$40
Total		**1,666,348**	**$856,824**	**100.0%**	**100.0%**	**$514**

(1) FBC 2006 = FBC 2004 with 2006 and 2007 supplements

Table 5-10 summarizes the losses avoided by building occupancy. The large contribution of one- and two-family dwellings to the total losses avoided is due primarily to their large share of the building inventory. On the other hand, the average loss avoided *per building* is greater in the other occupancies due to the much larger value per building.

Table 5-10: Florida Average Annual Losses Avoided by Occupancy

Occupancy	Total Post-2000 Bldg Count	Bldg Count Modeled(1)	SF Modeled (x1,000)	BRV Modeled ($M)	CRV Modeled ($M)	Total LA ($1,000)
One- and Two-Family Dwellings	1,503,290	1,503,257	3,295,351	$439,038	$219,519	$526,968
Other Residential	52,449	52,301	575,139	$85,594	$42,797	$103,303
Commercial	64,583	64,229	818,886	$99,374	$101,226	$177,924
Industrial	2,770	2,770	39,569	$4,219	$6,329	$4,833
Other	43,792	43,791	237,683	$32,358	$33,318	$43,796
Total	**1,666,884**	**1,666,348**	**4,966,628**	**$660,583**	**$403,189**	**$856,824**

(1) All buildings with adequate data to model

5.4.2 National Average Annual Losses Avoided

The hurricane wind losses avoided at the state level are summarized in Table 5-11. Despite contributing just 18% of the post-2000 buildings in the hurricane wind hazard area, Florida accounts for 81% of the national hurricane wind losses avoided due to its high hurricane risk, rapid growth, and early statewide adoption of I-Code (or similar) wind design requirements. The next leading states in terms of hurricane wind AALA contribution are South Carolina (6.4%), North Carolina (3.5%), Alabama (2.7%), Texas (2.6%), and Mississippi (1.3%). Each remaining state contributes less than 1.0%. Louisiana would have likely been included in the list of states contributing more than 1.0% if a more complete record of post-2000 construction had been available.

Table 5-11: Hurricane Wind Average Annual Losses Avoided by State

State	Total Post-2000 Bldg Count	Bldg Count Modeled(1)	SF Modeled (x1,000)	BRV Modeled ($M)	CRV Modeled ($M)	Total AALA ($1,000)
Alabama	351,452	351,452	891,888	$116,656	$74,259	$30,555
Connecticut	84,056	84,055	313,173	$62,989	$40,733	$1,247
Delaware	75,089	75,076	172,026	$29,379	$14,932	$967
District of Columbia	4,762	4,762	98,539	$16,319	$12,553	$3
Florida	1,666,880	1,666,348	4,966,628	$660,583	$403,189	$856,824
Georgia	873,229	873,229	2,630,667	$374,635	$220,286	$1,258
Hawaii	54,402	54,402	109,288	$21,063	$12,089	$1,569
Louisiana	96,775	96,775	302,443	$39,742	$28,316	$1,195
Maine	46,239	46,239	111,691	$16,099	$10,197	$6
Maryland	255,607	255,542	1,086,317	$175,233	$104,218	$1,010
Massachusetts	149,853	149,853	593,402	$116,646	$75,255	$5,178
Mississippi	218,613	218,613	510,249	$60,745	$39,165	$14,547
New Hampshire	71,295	71,294	208,503	$34,103	$21,356	$4
New Jersey	244,001	244,001	783,856	$171,930	$94,093	$7,368
New York	296,853	296,846	1,169,959	$241,836	$136,913	$5,562
North Carolina	870,695	870,586	2,582,844	$380,063	$227,450	$34,030
Pennsylvania	387,301	387,290	1,321,155	$222,918	$141,878	$3
Rhode Island	20,617	20,616	62,430	$11,610	$7,565	$1,354
South Carolina	415,687	415,686	1,079,864	$155,840	$89,047	$67,648
Texas	2,445,035	2,445,030	7,430,847	$1,009,707	$638,315	$28,751
Vermont	12,405	12,405	30,212	$4,687	$2,919	$0
Virginia	463,805	463,801	1,640,082	$275,638	$161,718	$1,613
West Virginia	96,367	96,366	187,607	$25,222	$13,539	$1
Total	**9,201,018**	**9,200,267**	**28,283,670**	**$4,223,642**	**$2,569,986**	**$1,060,692**

(1) All buildings with adequate data to model.

The following maps illustrate the hurricane wind inventory modeled, the AALs, and the AALAs at the county level:

- Figure 5-6 shows the percentage of the post-2000 buildings in each county that could be analyzed for hurricane wind losses avoided. Counties with inadequate data are shown in white. At least 97% of the post-2000 buildings were modeled in each of the other counties.
- Figure 5-7 shows the post-2000 BRV in dollars. This map highlights urban areas that have experienced rapid growth, such as Houston and Orlando.
- Figure 5-8 shows the pre-I-Code loss cost, which is defined as the AAL per $1,000 of BRV. Pre-I-Code loss costs are the normalized AALs that would have been expected if all of the post-2000 buildings had been built to pre-I-Code standards. This map highlights the areas of highest hurricane hazard.
- Figure 5-9 shows the I-Code (or similar code) loss cost using the same scale as Figure 5-8. Note the reductions in Florida loss costs, especially in the FBC HVHZ (Miami-Dade and Broward Counties).
- Figure 5-10 shows the AALA by county in dollars. Note the high AALAs in coastal Florida and a few coastal or very nearly coastal counties outside Florida, especially those with large growth since 2000 (e.g., Harris and Galveston Counties in Texas, Charleston and Horry Counties in South Carolina, and Brunswick County in North Carolina). There are many jurisdictions in the BCEGS states (Alabama, Georgia, Texas, Vermont, and West Virginia) that have no losses avoided because either the BCEGS data showed that an I-Code had not been adopted in time or the BCEGS data did not provide a building code history for the jurisdiction.
- Figure 5-11 shows the reduction in AAL as a percentage of the pre-I-Code AAL. In this map, the reductions along the coasts of Mississippi, Alabama, Florida, South Carolina, and North Carolina, and to a lesser extent Maryland, Delaware, New Jersey, Long Island (NY), southeastern Connecticut, Rhode Island, and Cape Cod (MA), are more uniform since these reductions are presented in relative rather than absolute terms.
- Finally, Figure 5-12 shows the contribution of each county to the national hurricane wind losses avoided. This map highlights the very large contribution of the coastal counties in South and Central Florida and the more moderate contributions of Northwest Florida, the coastal counties of Mississippi, Alabama, and the Carolinas, and two Texas counties (Harris and Galveston).

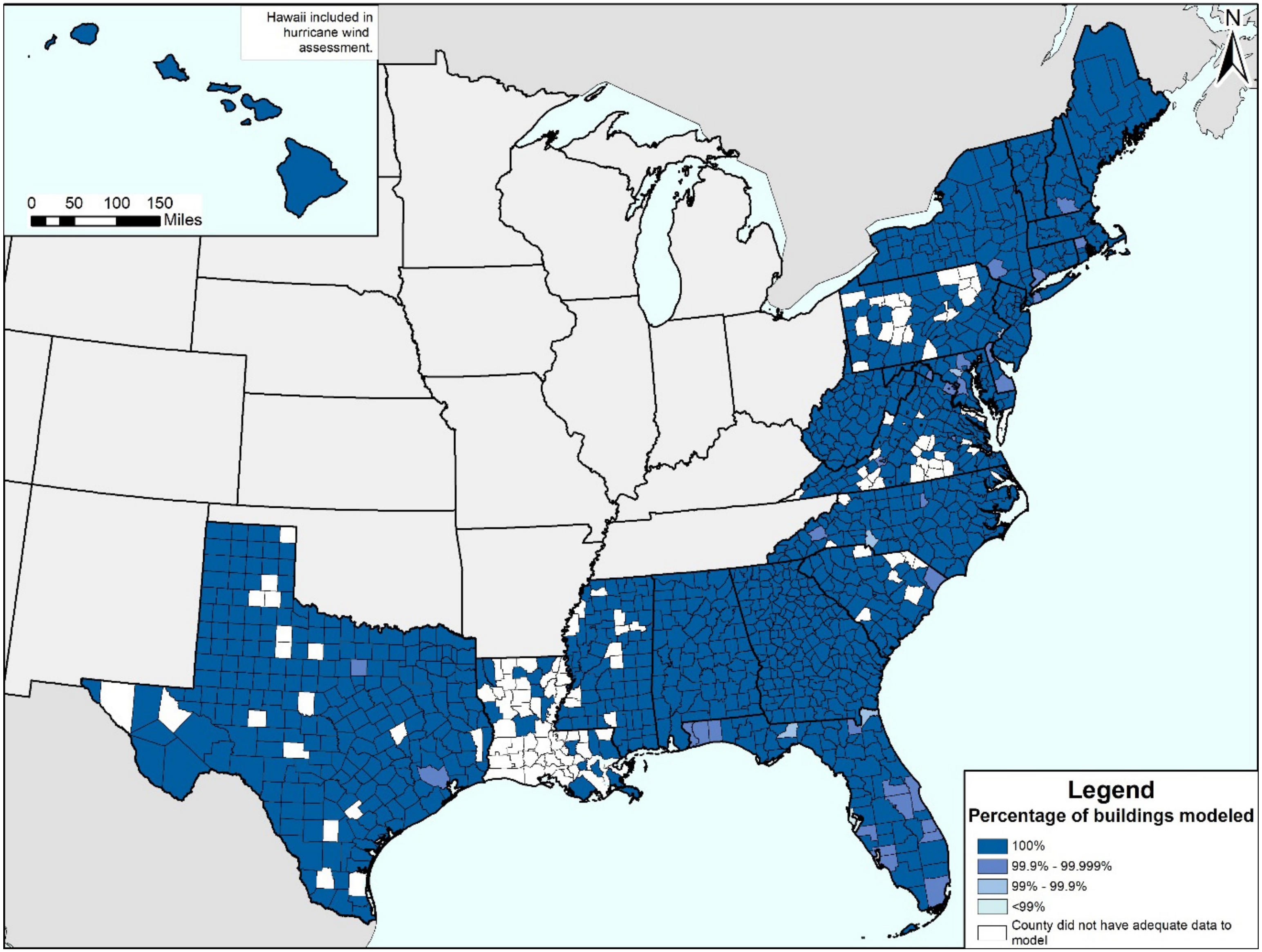


Figure 5-6: Percentage of buildings modeled

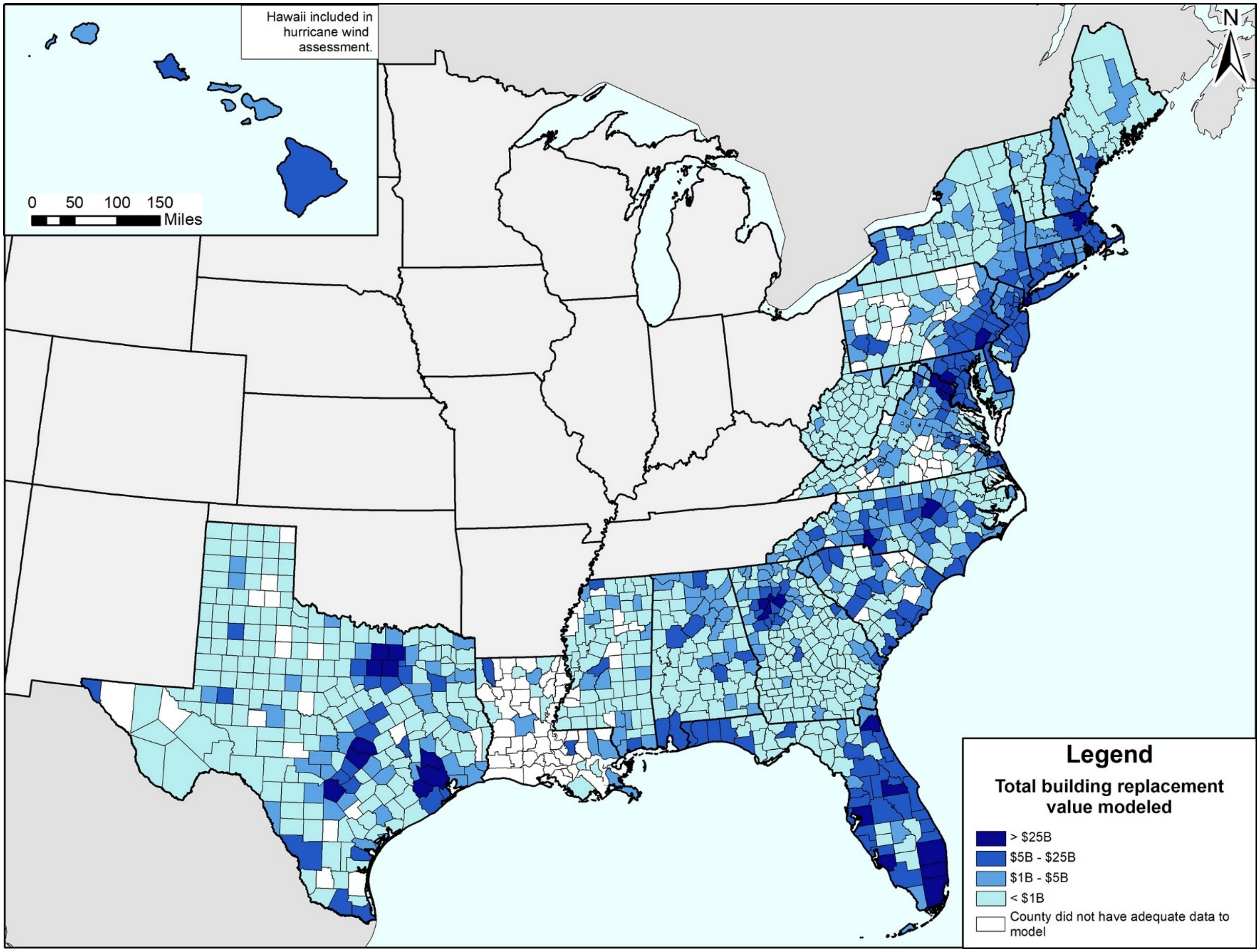


Figure 5-7: Building replacement value modeled

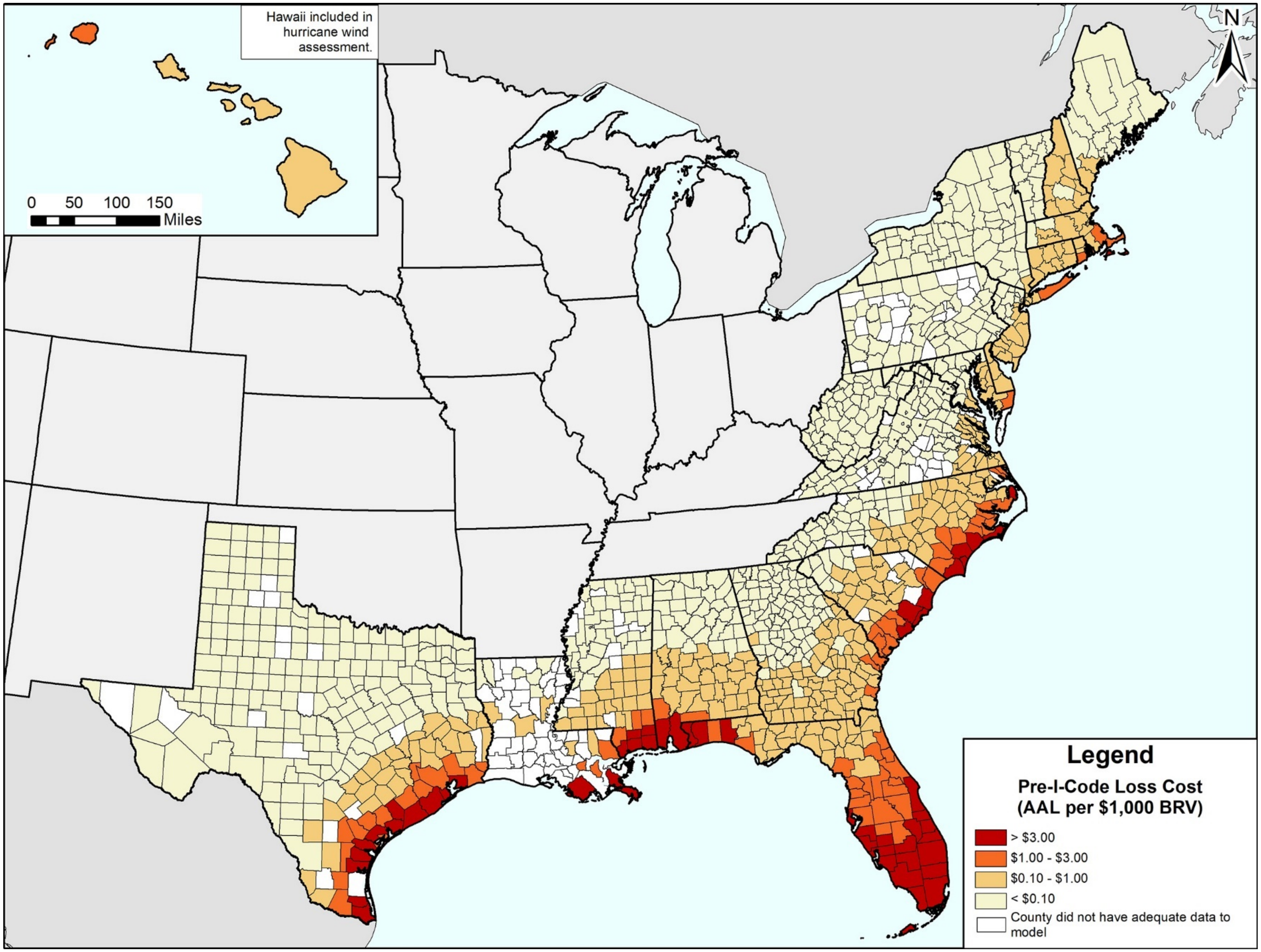


Figure 5-8: Pre-I-Code loss cost (AAL per $1,000 BRV)

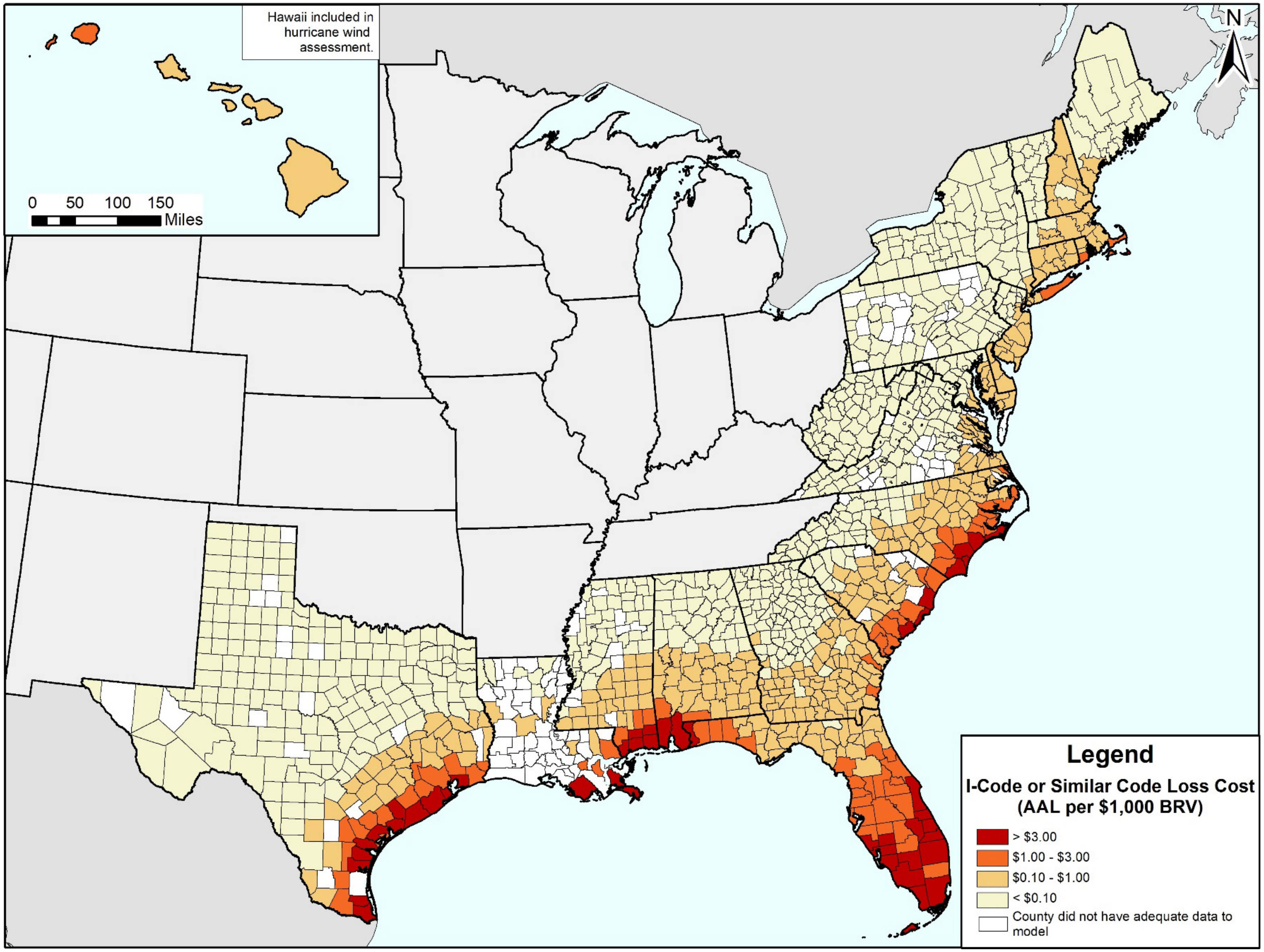


Figure 5-9: I-Code (or similar code) loss cost (AAL per $1,000 BRV)

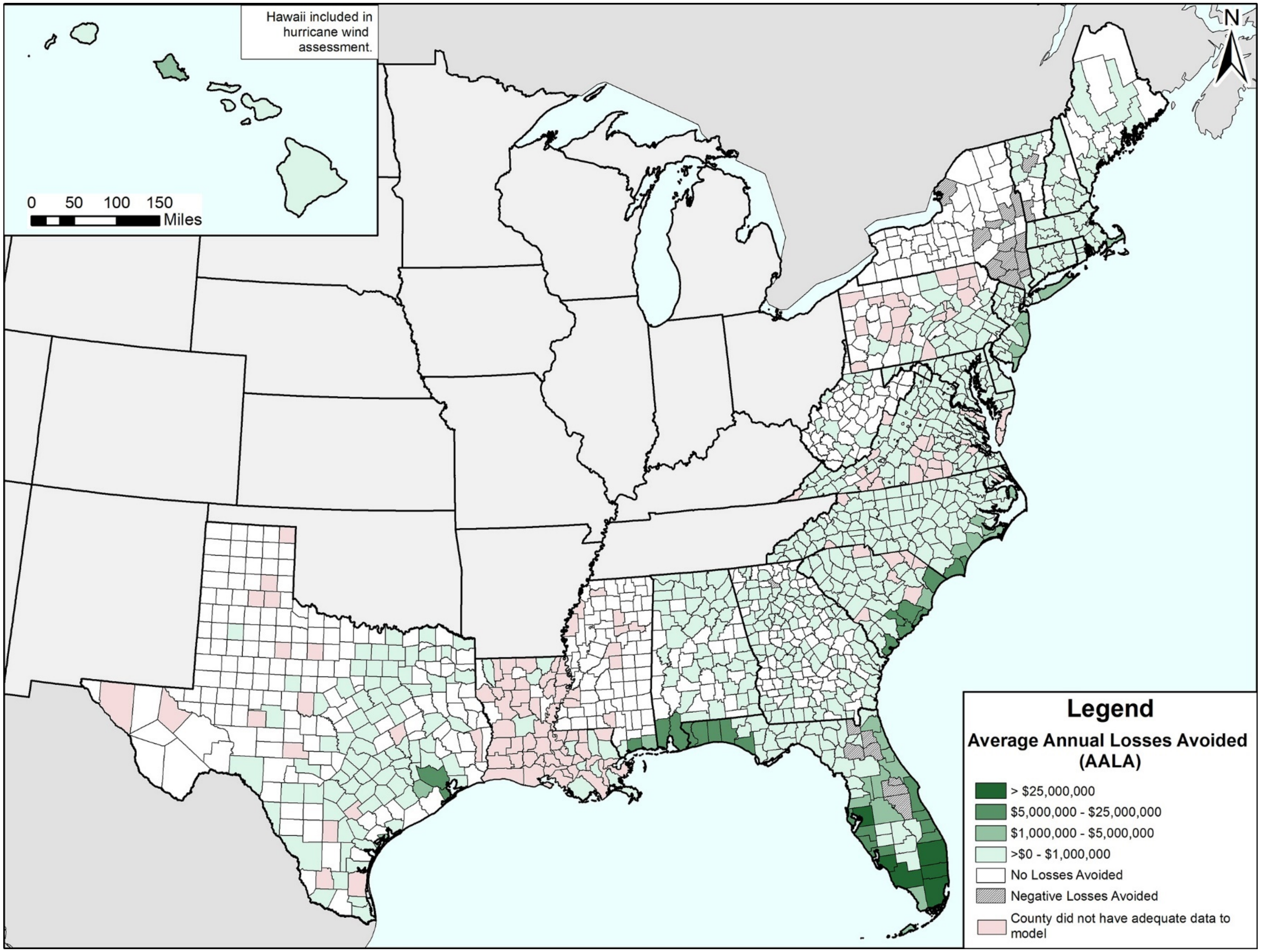


Figure 5-10: Average Annual Loss Avoided (AALA)

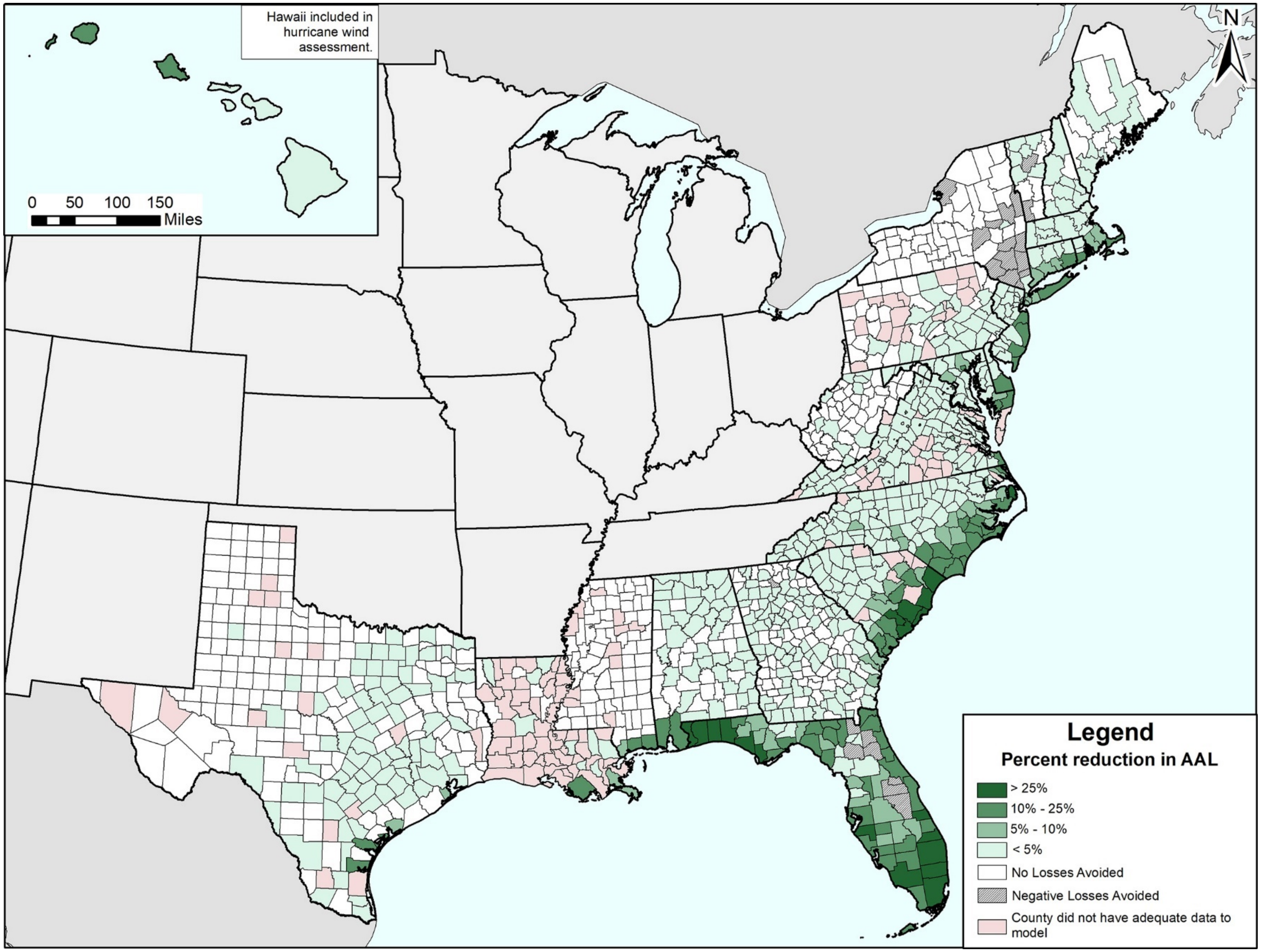


Figure 5-11: Percent reduction in AAL from pre-I-Code to I-Code (or similar code)

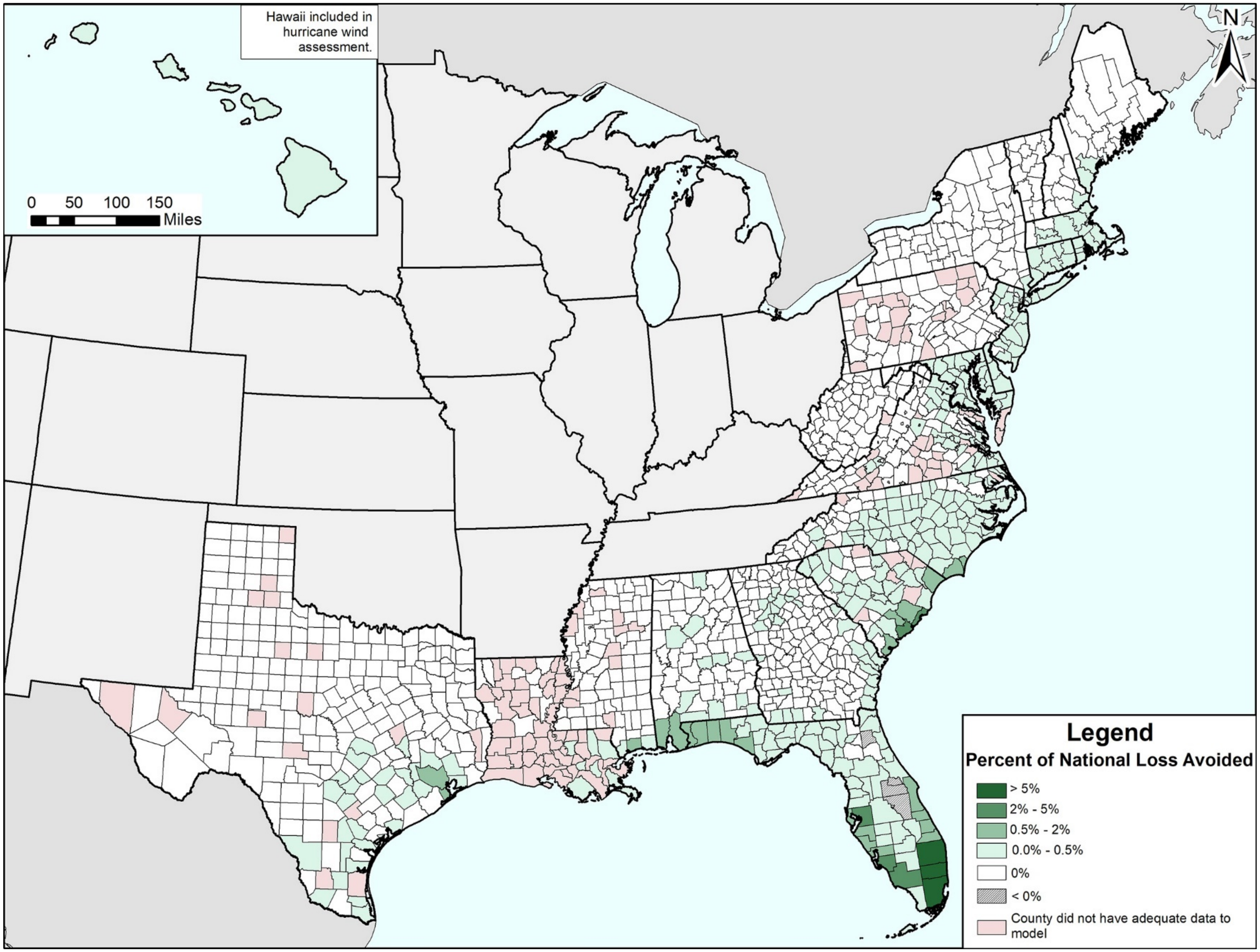


Figure 5-12: Percentage of national loss avoided (AALA)

Figure 5-10, Figure 5-11, and Figure 5-12 also identify, in gray with cross-hatching, a few counties with small negative losses avoided (i.e., a small increase in expected losses from the pre-I-Code case to the I-Code case). There are two main issues contributing to negative losses avoided. First, and most important, are the changes in the basic wind speed maps between ASCE 7-93 and ASCE 7-98, particularly in Central Florida. Looking at the ASCE 7-98 basic wind speed maps in Figure 5-3, one can see the 100 mph 3-second gust contours extending almost to Orlando and the 110 mph contour extending into most of Seminole, Orange, and Osceola Counties. On the previous map (ASCE 7-93, Figure 5-2), however, all of Central Florida, both coastal and inland, was within the 100 mph fastest mile contour, which corresponds to a 3-second gust of about 118 mph. Thus, many buildings constructed in Central Florida from 2003 to 2012 could have been designed for lower wind pressures than they would have been had the ASCE 7-93 map remained in effect.

The second, and less significant, source of negative losses avoided is in jurisdictions that used BOCA prior to adopting an I-Code. BOCA required all C&C to be designed as if located in open terrain (Exposure C), whereas the I-Codes permit the use of suburban terrain (Exposure B) where appropriate. Thus, all else being equal, the design C&C loads required under the I-Codes can be lower than the design loads required under BOCA. However, due to differences in basic wind speed maps and pressure coefficients, the actual design loads for C&C under the I-Codes in Exposure B are generally higher than BOCA design loads, except in areas of relatively low wind hazard. This issue is the cause of the small negative losses avoided indicated by the gray with cross-hatching in parts of upstate New York and New England in Figure 5-10 and Figure 5-11 However, as indicated by the white shading for these counties in Figure 5-12, these small negative losses avoided are negligible in terms of their contribution to the national wind losses avoided.

5.4.3 Savings Based on Year of Construction

Looking ahead, losses avoided will continue to increase each year as more jurisdictions adopt I-Codes and design standards. However, the rate of increase will depend both on where new construction occurs and the diligence with which states and local jurisdictions adopt and enforce current codes.

Figure 5-13 plots the national hurricane wind losses avoided as a percentage of the baseline pre-I-Code AAL. For hurricane wind losses, there was an initial 15 to 20% in savings, resulting primarily from the code editions that were published after Hurricane Andrew in 1992, namely the 1994 SFBC, 2001 FBC, and 2000 IBC. In 2008, the savings jumped to about 35% with the introduction of windborne debris protection requirements and other improvements in the 2006 IBC and the 2006/2007 amendments to the 2004 FBC following the hurricanes in 2004 and 2005. From 2008 to 2016, there was a gradual improvement in savings up to about 40% as additional hurricane-prone jurisdictions adopted the 2006, 2009, 2012, and 2015 editions of the IBC and IRC. Finally, there are preliminary indications of another jump starting in 2017, which

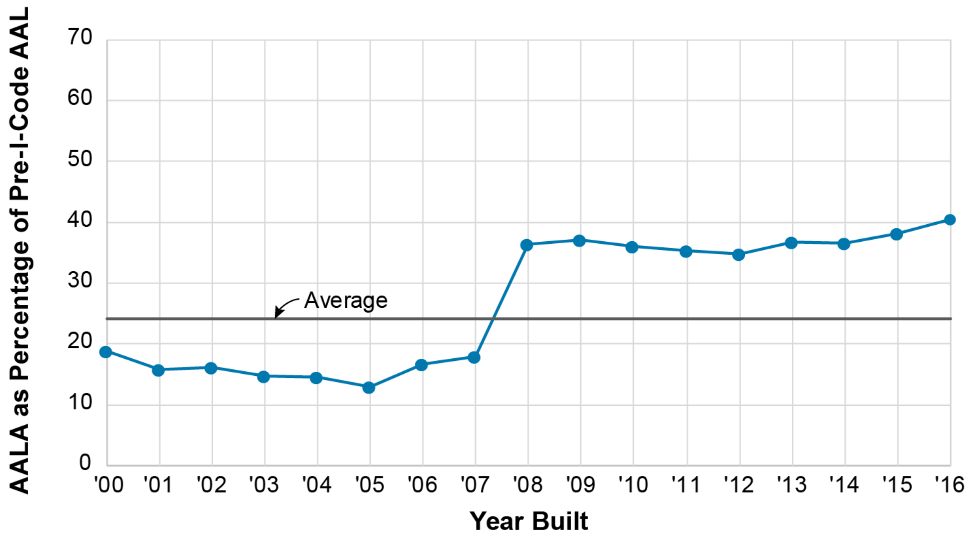


Figure 5-13: Losses avoided as a percentage of pre-I-Code AAL by year built

may be partially attributable to improved wind-loading criteria for low-rise roofs in ASCE 7-16. However, the precise magnitude of this most recent increase in savings is unclear due to the limited quantity of 2017 and 2018 construction data that were available in time for this study.

CHAPTER 6
Seismic Hazard Analysis

This chapter summarizes the methodology that was used to estimate seismic Average Annual Losses Avoided (AALA) for buildings and their contents for the approximately 1.4 million buildings that were constructed from 2000 to 2018 in the six western states with the highest seismicity. The states are Alaska, California, Hawaii, Oregon, Utah, and Washington and are referred to as the seismic hazard study area or six western seismic states.

The approach to evaluating losses avoided for seismic hazards focused on implementing the Hazus earthquake loss estimation methodology (FEMA, 2012c), specifically the Hazus Advanced Engineering Building Module (AEBM) (FEMA, 2012b) for the seismic hazard study area. The six western seismic states represent 78.5% of the national AAL as estimated by FEMA using Hazus (FEMA, 2017). For reference, the eight New Madrid Seismic Zone (NMSZ) states (Alabama, Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee) represent an additional 7.8% of the national AAL (see Appendix F, Section F.5, for more information on potential modeling of the NMSZ), and South Carolina represents 1.9% (FEMA, 2017). See FEMA (2017) for the list of AALs by state.

The selection of the six western seismic states for modeling was based on their high seismicity, AALs and also because the states were early adopters of the seismic design provisions in the Uniform Building Code (1997 UBC) (ICBO, 1997), which were carried into the I-Codes, to illustrate cases in which the states have already accrued benefits of code adoption. While the seismicity in the NMSZ is lower than in the western seismic states, the exposure is similar (see Appendix F); their code adoption history creates an opportunity for additional estimates of losses avoided (see Appendix F.5).

The primary challenges in the seismic portion of this study were (1) determining the seismic code adoption histories throughout the region, (2) establishing the appropriate Hazus Design Levels assignment methodology, based on the lateral strength of each building, and developing new Design Levels when necessary, and (3) determining the Hazus Model Building Type (MBT) (see Table 6-1) for each building record based on information in the CoreLogic building database. The Hazus earthquake loss estimation methodology contains a variety of models for structural systems (Table 6-1); models for nonstructural systems (both drift-sensitive and acceleration-sensitive) are implicitly associated with the structural models (FEMA, 2012c). Typical nonstructural components are listed in Table 6-2. All three challenges will have a major impact on the determination of seismic losses avoided as building codes are revised, updated, and adopted.

Table 6-1: Hazus Model Building Types

Description	Model Building Type	Height (Number of Stories)
Wood, light frame (≤5000 SF)	W1	1 to 2 stories
Wood, commercial and industrial (>5000 SF)	W2	All
Steel moment frame	S1L	Low-rise (1 to 3 stories)
	S1M	Mid-rise (4 to 7 stories)
	S1H	High-rise (8+ stories)
Steel-braced frame	S2L	Low-rise (1 to 3 stories)
	S2M	Mid-rise (4 to 7 stories)
	S2H	High-rise (8+ stories)
Steel light frame	S3	All
Steel frame with cast-in-place concrete shear walls	S4L	Low-rise (1 to 3 stories)
	S4M	Mid-rise (4 to 7 stories)
	S4H	High-rise (8+ stories)
Steel frame with unreinforced masonry infill walls	S5L	Low-rise (1 to 3 stories)
	S5M	Mid-rise (4 to 7 stories)
	S5H	High-rise (8+ stories)
Concrete moment frame	C1L	Low-rise (1 to 3 stories)
	C1M	Mid-rise (4 to 7 stories)
	C1H	High-rise (8+ stories)
Concrete shear walls	C2L	Low-rise (1 to 3 stories)
	C2M	Mid-rise (4 to 7 stories)
	C2H	High-rise (8+ stories)
Concrete frame with unreinforced masonry infill walls	C3L	Low-rise (1 to 3 stories)
	C3M	Mid-rise (4 to 7 stories)
	C3H	High-rise (8+ stories)
Precast concrete tilt-up walls	PC1	All
Precast concrete frames with concrete shear walls	PC2L	Low-rise (1 to 3 stories)
	PC2M	Mid-rise (4 to 7 stories)
	PC2H	High-rise (8+ stories)
Reinforced masonry bearing walls with wood or metal deck diaphragms	RM1L	Low-rise (1 to 3 stories)
	RM1M	Mid-rise (4 to 7 stories)
Reinforced masonry bearing walls with precast concrete diaphragms	RM2L	Low-rise (1 to 3 stories)
	RM2M	Mid-rise (4 to 7 stories)
	RM2H	High-rise (8+ stories)
Unreinforced masonry bearing walls	URML	Low-rise (1 to 3 stories)
	URMM	Mid-rise (4 to 7 stories)
Mobile homes	MH	All

Table 6-2: Typical Nonstructural Components

Type	Component	Drift-Sensitive	Acceleration-Sensitive
Architectural	Nonbearing walls/partitions	P	S
	Cantilever elements and parapets		P
	Exterior wall panels	P	S
	Veneers and finishes	P	S
	Penthouses	P	
	Racks and cabinets		P
	Access floors		P
	Appendages and ornaments		P
Mechanical/ Electrical	General mechanical equipment		P
	Manufacturing and process machinery		P
	Piping systems	S	P
	Storage tanks and spheres		P
	HVAC systems (e.g., chillers, ductwork)	S	P
	Elevators	S	P
	General electrical (e.g., switchgear, ducts)	S	P
	Lighting fixtures		P

Source: FEMA (2012c)
P = Primary cause of damage; S = secondary cause of damage

Losses avoided as a result of implementing and enforcing seismic building codes can result from an increase in the seismic hazard level that buildings are required to resist (i.e., seismic hazard maps change over time, most often increasing) or from changes to code design provisions that are intended to make buildings more resistant to damage. The losses from damage in any one earthquake depend primarily on the level of shaking, the vulnerability of the exposed inventory, which varies with the age (which determines which code was used in the design and the resulting building strength), and the types of buildings (e.g., occupancy, structural material) that were subjected to the event.

The seismic analysis methodology focused on modeling the losses avoided associated with the adoption of seismic provisions in building codes. The main components of the methodology were the following:

- **Seismic code adoption**: Determining which communities had adopted I-Codes (or similar codes) from BCEGS state data and local data (see Section 6.1 and Appendix F, Section F.1).
- **Seismic hazard data**: Determining local soil conditions and structure exposure to near-fault and other seismic hazard zones (see Appendix F, Section F.2).

- **Seismic modeling**: Determining the appropriate Hazus Design Levels and MBTs for each structure and calculating AALs and losses avoided related to building and contents damage (see Section 6.2 and Appendix F, Section F.3).

6.1 Seismic Code Adoption

This section provides an overview of the code adoption history for the seismic hazard study area, including the pre-IBC code (see Section 6.1.1 for information on the pre-IBC code).

Understanding the history of building code development and adoption in the seismic hazard study area was necessary to develop the Design Level assignments for each code edition that was included in the study.

The code history in the six western seismic states is simpler than in other regions because four of the six states (California, Oregon, Washington, and Utah) had statewide code mandates before 2000. Alaska and Hawaii implemented statewide mandates after 2000.

Updates to Seismic Provisions

Over the last two decades, the seismic provisions in the U.S. model building codes and national standards have been updated regularly based on the latest National Earthquake Hazards Reduction Program *(NEHRP) Recommended Seismic Provisions for New Buildings and Other Structures* (FEMA, 2015a), which evaluates and translates the latest new knowledge and technologies for improving seismic performance of new buildings. It is generally recognized that a code-compliant new building typically provides better seismic protection and is more cost-effective than retrofitted seismically vulnerable buildings (FEMA, 2020b).

Because of their experience with relatively frequent earthquakes, the six western seismic states adopted and enforced seismic provisions in building codes long before the year 2000; all of the provisions before 2000 were based on the UBC. In all areas of the six western seismic states except for the several counties in Hawaii and parts of Alaska that do not have residential building codes, the 1997 UBC was in place immediately before the initial adoption of the I-Codes.

6.1.1 Identification of the Pre-IBC Code

For the purposes of this study, the 1997 UBC was judged to be similar to the I-Codes and parallel to but not exactly the same as the 2000 IBC. Consequently, to estimate the losses avoided as a result of adopting I-Codes or similar building codes in this study, the 1994 UBC, which was in place prior to the 1997 UBC, was the pre-I-Code code that was compared to the codes in place at the time of construction. For additional discussion, see Appendix F, Section F.1.1.

6.1.2 History of Code Requirements for One- and Two-Family Dwellings

Seismic building codes have traditionally not required fully engineered design for one- and two-family dwellings (in Hazus, Residential 1/RES1 and Residential 3A/RES3A Occupancies). Larger homes, however, were often designed by architects and engineers at the owner’s request and were assumed to have been constructed in accordance with seismic building codes. These buildings are essentially all wood light frame construction (in Hazus, MBT W1). Prescriptive provisions for such buildings, called “conventional construction,” have been included in the UBC since 1970. Similar but slightly more detailed provisions were put into the IRC when it was developed.

Such residences qualify for use of the prescriptive provisions unless they have a hazard assignment using S_{DS} greater than 1.25, in which case a fully engineered design is required. S_{DS} is the design spectral response acceleration parameter at short periods, developed by a code formula based on mapped hazard values and site soils factors. Other criteria for fully engineered design include irregularity and height limitations, which were not addressed in this study. Because houses constructed to these prescriptive provisions vary in configuration and because code requirements may not be enforced to the same extent as for an engineered design, houses built using these rules were judged to be slightly more prone to damage than fully engineered designs and were uniformly assigned a Hazus Design Level of Moderate Code (see Appendix F, Section F.3.1).

In addition, the IRC has not always been adopted in parallel with the corresponding IBC. Therefore, the rules for setting Hazus parameters for these residences differed from other buildings, and the code histories were separated.

6.1.3 Code Histories by State

Most states adopt seismic provisions from a model code and include the provisions in their state code. Each state has a different name for its state code; for example, California adopts the California Building Code, and Oregon adopts the Oregon Structural Specialty Code for commercial buildings and the Oregon Residential Specialty Code for residential construction. For simplicity, Hazus Design Levels for this study were determined from the base model codes: the UBC, IBC, or IRC. Code histories, presented in Table 6-3 for commercial structures and Table 6-4 for residential structures, were therefore developed using the base codes embedded in the state adoptions. The code histories reflect the year in which codes were adopted; as noted in Section 2.4.3, a 1-year time lag was applied to the dates to reflect the likely code under which buildings were designed. Code adoption histories for California, Oregon, Utah, and Washington are provided at the state level; histories for Hawaii are provided at the county level; and histories for Alaska are provided at the city and borough levels. Narratives for each state’s code adoption history are provided in Appendix F, Section F.1.

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Table 6-3: Commercial Code Adoption Histories by State

State	County / Borough	City	Commercial Code Adoption Histories by State																			
			1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
AK	All	All	UBC 1997		IBC 2000				IBC 2003		IBC 2006					IBC 2009					IBC 2012	
	Fairbanks North Star	Fairbanks	UBC 1997			IBC 2000			IBC 2003			IBC 2006			IBC 2009					IBC 2015		
	Kenai Peninsula	Kenai	UBC 1997				IBC 2000		IBC 2003			IBC 2006					IBC 2009					
	Ketchikan Gateway	Ketchikan	UBC 1994	UBC 1997					IBC 2003					IBC 2006			IBC 2012					
	Matanuska-Susitna	Palmer	UBC 1997							IBC 2003		IBC 2006			IBC 2009						IBC 2015	
	Anchorage	Anchorage inside BSSA	UBC 1997				IBC 2000		IBC 2003			IBC 2006			IBC 2009					IBC 2012		
	Juneau	Juneau	UBC 1997					IBC 2003					IBC 2006					IBC 2009			IBC 2012	
CA	All	All	UBC 1997									IBC 2006			IBC 2009			IBC 2012			IBC 2015	
HI	All	All	None											IBC 2006								IBC 2012
	City / County of Honolulu	All	UBC 1994	UBC 1997							IBC 2003					IBC 2006						
	Hawaii	All	UBC 1991 w/Zone 4[1]													IBC 2006						
	Maui	All	UBC 1994	UBC 1997												IBC 2006						
	Kauai	All	UBC 1991		UBC 1997							IBC 2003				IBC 2006						
OR	All	All	UBC 1997					IBC 2003			IBC 2006			IBC 2009				IBC 2012				
UT	All	All	UBC 1997			IBC 2000		IBC 2003			IBC 2006			IBC 2009			IBC 2012			IBC 2015		
WA	All	All	UBC 1997					IBC 2003			IBC 2006			IBC 2009			IBC 2012			IBC 2015		

(1) UBC 1991 and UBC 1991 w/ Zone 4 are assumed equivalent to UBC 1994 (pre-I-Code)
BSSA = Building Safety Service Area
IBC = International Building Code
UBC = Uniform Building Code

Table 6-4: Residential Code Adoption Histories by State

State	County / Borough	City	Residential Code Adoption Histories by State 1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
AK	All	All	None																			
	Fairbanks North Star	Fairbanks	UBC 1997			IRC 2000			IRC 2003			IRC 2006			IRC 2009					IRC 2015		
	Kenai Peninsula	Kenai	UBC 1997				IRC 2000		IRC 2003			IRC 2006					IRC 2009			IRC 2012		
	Ketchikan Gateway	Ketchikan	UBC 1994	UBC 1997					IRC 2003					IRC 2006			IRC 2012					
	Matanuska-Susitna	Palmer	UBC 1997							IRC 2003		IRC 2006			IRC 2009						IRC 2015	
	Anchorage	Anchorage inside BSSA	UBC 1997				IRC 2000		IRC 2003			IRC 2006			IRC 2009					IRC 2012		
	Juneau	Juneau	CABO 1995					IRC 2003					IRC 2006					IRC 2009			IRC 2012	
CA	All	All	UBC 1997									IBC 2006			IRC 2009			IRC 2012			IRC 2015	
HI	All	All	None																			IRC 2012
	City / County of Honolulu	All	UBC 1994	UBC 1997							IRC 2003					IRC 2006						
	Hawaii	All	UBC 1991 w/Zone 4[1]													IRC 2006						
	Maui	All	UBC 1994	UBC 1997												IRC 2006						
	Kauai	All	UBC 1991		UBC 1997							IRC 2003				IRC 2006						
OR	All	All	CABO 1995	CABO 1998[2]			IRC 2000		IRC 2003			IRC 2006			IRC 2009						IRC 2015	
UT	All	All	UBC 1997			IRC 2000		IRC 2003			IRC 2006			IRC 2009			IRC 2012			IRC 2015		
WA	All	All	UBC 1997					IRC 2003				IRC 2006		IRC 2009			IRC 2012			IRC 2015		

(1) UBC 1991 and UBC 1991 w/ Zone 4 are assumed equivalent to UBC 1994 (pre-I-Code)
(2) CABO 1998 is assumed to be equivalent to UBC 1997 for one- and two-family dwellings
BSSA = Building Safety Service Area
CABO = Council of American Building Officials
IBC = International Building Code
IRC = International Residential Code
UBC = Uniform Building Code

6.2 Seismic Modeling Methodology

This section provides an overview of the methodology that was used to estimate seismic AALs and losses avoided. In addition, a summary of the final analysis database for the seismic hazard study area is provided and the approach to estimating AALs is described.

As noted above, two of the challenges in the seismic portion of this study were (1) establishing appropriate Hazus Design Levels (based on the lateral strength of each building) or developing new Design Levels when necessary, and (2) determining the Hazus MBT (see Table 6-1) for each building record based on information in the CoreLogic building database.

Figure 6-1 is a flowchart of the seismic methodology steps and the data inputs. The seismic-specific section of the methodology is delineated by the dashed red line; the remainder of the approach is similar across the hazards. Selected fields from the post-2000 CoreLogic database (occupancy class, square footage, height, location and year built) fed into various categorization schemes, allowing the development of a database that could be analyzed using the Hazus AEBM (FEMA, 2012b).

- Building occupancy and square footage were used with the updated Hazus Replacement Cost Models (see Section 3.2.3) to estimate BRVs and CRVs for each building.
- Building occupancy, square footage and height were used to develop state-level profiles, which served as a guide for discussions with local Structural Engineers (see Appendix F, Section F.3.2). With their input, MBT relationships were developed for each state. The relationships were used to assign an MBT to each building.
- Year built is used with the collected code adoption histories (see Section 6.1.3) to identify which code was in place at the time of the building's construction.
- Georeferenced soils data (see Appendix F, Sections F.2.2 and F.3.1.2) and code-specific seismic hazard maps (see Appendix F, Section F.2.3) were used to estimate required building design strengths under each building code edition to develop a library of census tract Design Levels (see Appendix F, Section F.3.1). For each building, a look-up using the census tract location and the code in place at the time of construction yielded the as-built or I-Code Hazus Design Level, along with the assumed Design Level for the pre-I-Code code.

The updated building data record, now including an MBT and Design Level, was fed into the Hazus AEBM, which used USGS probabilistic seismic hazard data (see Appendix F, Section F.2.1) to estimate each building's I-Code and pre-I-Code AAL (see Section 6.2.2); the difference between the two AAL estimates is the Average Annual Losses Avoided (AALA).

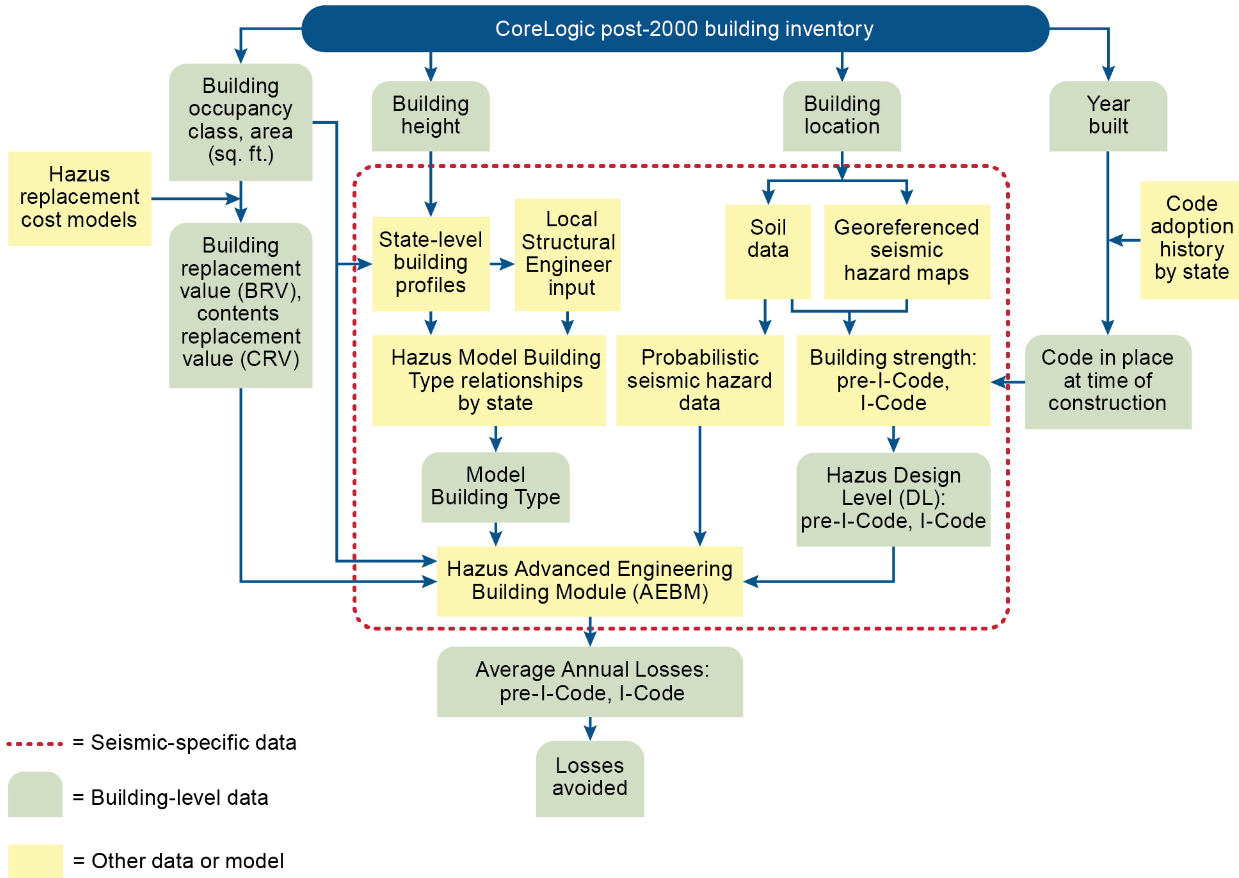

Figure 6-1: Seismic methodology

6.2.1 Development of Final Analysis Datasets

The baseline parcel database of post-2000 construction developed for use in this study contained more than 2.45 million records for the six western seismic states included in the assessment. In each state, analyses were focused on the Hazus Occupancy Classes (see Table 3-1) representing the majority of exposure.

For example, in California, records for the top 16 occupancies (by building square footage) were included, representing 96% of records in the final GIS data set, 97% of total building square footage, and 97% of building replacement value. In addition, a handful of California records were omitted because of data issues or inconsistencies (15 in California) or because their final location fell outside the boundaries of the Hazus census tracts (45 in California) and their inclusion would have caused Hazus to crash. The top occupancies included in each

Final Earthquake Analysis Database

The final post-2000 building database used in the seismic assessment included more than 2.4 million buildings valued at $1.4 trillion.

- Most of the exposure (65%) is in California.
- One- and two-family dwellings represent 92% of the building count and 67% of the building value.

state's assessment are identified in Table 6-5 and are listed in the order in which the analyses were conducted. Table 6-6 provides a state-level summary of the final analysis databases. Overall, the final databases for the six western seismic states included 99.5% of all buildings in the post-2000 processed CoreLogic database, and included approximately 7.9 billion square feet of buildings valued at more than $1.4 trillion.

Table 6-5: Top Occupancies Analyzed in Each Seismic State

Occupancy[(1)]	CA	OR	WA	UT	AK	HI
AGR1	X	X	X	X		
COM1	X	X	X	X	X	
COM2	X	X	X	X	X	X
COM3					X	
COM4	X	X	X	X	X	X
COM7	X	X	X			
COM8	X		X		X	
COM10	X		X		X	
EDU1		X	X	X		
GOV1		X				
IND2	X	X	X	X	X	
IND4					X	
RES1	X	X	X	X	X	X
RES3A	X	X	X	X	X	X
RES3B	X	X	X	X	X	X
RES3C	X	X	X	X	X	X
RES3D	X	X	X	X		
RES3E	X	X	X	X		
RES3F	X	X	X	X		
RES4	X		X		X	X
RES6			X			
Count	**16**	**15**	**18**	**13**	**13**	**7**

(1) See Table 3-1 for Hazus Occupancy Class Definitions

Table 6-6: Summary of Post-2000 Data included in the Final Analysis for the Six Western Seismic States

State	Total Post-2000 Building Count	Building Count in Final Analysis Database	Square Feet in Final in Analysis Database (1,000 SF)	BRV in Final Analysis Database ($M)	CRV in Final Analysis Database ($M)
Alaska	41,288	41,055	82,497	$15,726	$8,673
California	1,343,773	1,337,104	4,834,826	$914,309	$537,208
Hawaii	54,402	54,162	108,264	$20,877	$11,969
Oregon	249,911	249,159	612,905	$95,020	$56,002
Utah	254,486	252,990	687,000	$96,305	$54,575
Washington	510,178	507,453	1,594,263	$261,950	$159,259
Total	**2,454,038**	**2,441,923**	**7,919,755**	**$1,404,187**	**$827,686**

A summary of the analysis data for the six western seismic states is provided in Table 6-7 by general occupancy. As shown, residential construction makes up the majority of the exposure. One- and two-family dwellings (Hazus Occupancy Classes RES1 and RES3A), governed by the IRC, account for 92% of records, 65% of square footage, and 67% of building value. Other residential construction, including multi-family dwellings, represents an additional 3% of records, 15% of square footage, and 16% of building value.

Table 6-7: Summary of Post-2000 Data included in the Final Analysis for the Six Western Seismic States by General Occupancy

General Occupancy	Building Count	Square Feet (1,000 SF)	BRV ($M)	CRV(1) ($M)
One- and Two-Family Dwellings	2,246,160	5,173,847	$944,482	$472,241
Other Residential	76,186	1,207,307	$229,676	$114,838
Commercial	68,515	1,291,861	$195,258	$196,840
Industrial	7,163	136,775	$17,992	$26,988
Other(2)	43,899	109,964	$16,779	$16,779
Total	**2,441,923**	**7,919,755**	**$1,404,187**	**$827,686**

(1) Hazus content values are estimated as a percent of structure value; residential occupancies use 50%, commercial and industrial occupancies use either 50% (e.g., COM10), 100% (e.g., COM1, COM4) or 150% (e.g., COM7, IND2). See Table 3-1 for the Hazus Occupancy Class definitions.

(2) Other occupancies include agriculture, education, and government uses.

6.2.1.1 Advanced Engineering Building Module Inputs Based on Occupancy, Structure Type, and Design Level

In the Hazus AEBM, vulnerability functions are applied based on each building's profile, a combination of the assigned Hazus Occupancy, MBT, and Design Level (FEMA, 2012b). Two sets of profiles were generated for each building in the study, reflecting each building's current (i.e., as designed) Design Level under I-Code or equivalent requirements and a hypothetical pre-I-Code design, reflecting the Design Levels that would have been expected if the I-Codes had not been implemented. The original default Design Levels in Hazus were developed for UBC 1994, which is assumed to be the pre-I-Code condition (see Appendix F, Section F.3.1.1). In the BCS Study, a single MBT was applied to each building. To reflect the change in design strength between pre-I-Code and I-Code (or similar code) construction, the Hazus Design Level is modified, based on the site hazard (i.e., building code hazard map) at the time of design.

6.2.2 Hazus Earthquake AAL and Customization of the Hazus AEBM Code

Seismic Average Annual Losses

Seismic AALs are calculated from losses for the following return periods:

- 100-year
- 250-year
- 500-year
- 750-year
- 1,000-year
- 1,500-year
- 2,000-year
- 2,500-year

Hazus uses probabilistic seismic hazard data to compute seismic AAL estimates. The data are derived from the National Seismic Hazard Maps (Petersen et al., 2014) for eight return periods (100-, 250-, 500-, 750-, 1000-, 1500-, 2000-, and 2500-year return periods); see Appendix F, Section F.2.1. Losses are computed for each return period and combined to estimate the AAL. As described in the *Hazus-MH Earthquake Model Technical Manual* (FEMA, 2012c), the AAL can be approximated by estimating the shaded area under the loss-probability curve (see Figure 6-2) by multiplying the sum of the return period losses by their annual probability of occurrence.

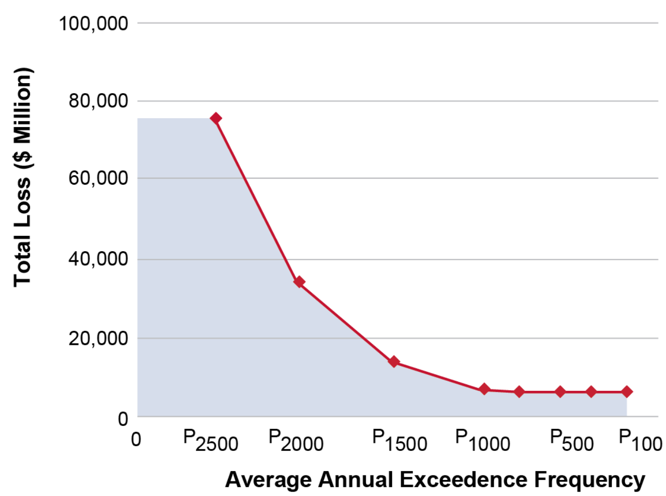

Figure 6-2: Example of a Hazus loss-probability curve (FEMA, 2012c)

In its standard configuration, Hazus does not include computation of the AAL as an automated option for the AEBM; AAL calculations are available only for the estimation of economic losses associated with the General Building Stock (GBS). Deriving the AAL estimates for the thousands of buildings analyzed would require conducting an AEBM analysis for each return period and extracting the results to external databases (i.e., outside Hazus) where they would need to be combined according to the Hazus AAL methodology.

Due to the multi-state scope and scale of the national study, this manual method of determining the AAL for AEBM results was expected to be both data- and time-intensive. To streamline the repetitive, labor-intensive manual runs and the required post-processing, a modified version of the Hazus code was developed to allow for a one-click execution of the AAL analysis for the

AEBM, using the same logic and code structure as the GBS AAL. All modified code was shared with the Hazus development team for review and for potential incorporation into Hazus.

6.3 Seismic Modeling Results

This section presents the results for the seismic modeling, including AAL, AALA, and normalized loss ratios. It explains the occurrence of negative losses avoided, describes the impact on losses of buildings with no change in Design Level, and highlights the large losses avoided for a unique residential construction type in Hawaii.

Earthquake Analysis Summary

- Conducted in six western states with the highest seismicity (Alaska, California, Hawaii, Oregon, Utah and Washington)
- Around 2.44 million post-2000 buildings analyzed
- Total AALA approximately $59.9 million

6.3.1 Average Annual Losses and Losses Avoided

Table 6-8 provides a summary of estimated AALs and losses avoided (AALAs) for building and contents damage for the pre-I-Code and I-Code (or similar code) representations of the post-2000 inventory for all modeled buildings in the six western seismic states. For similar results tabulated by county for each state, see Appendix A, Section A.1; for a discussion of the California county results, see Appendix F, Section F.4.2. As shown in Table 6-8, the total AAL for post-2000 construction designed under the pre-I-Code codes is $726 million, relative to $666 million for I-Code design, resulting in a $60 million (8%) AALA.

While the Hazus earthquake methodology allows for the calculation of additional direct economic losses beyond building and contents damage (i.e., business inventory losses and income losses), similar computations are not possible in the flood or hurricane methods applied here. Accordingly, for consistency across the various hazards, inventory and income loss results are not included in the seismic assessment (see Appendix F, Section F.4.2, for a discussion of these estimates for the California demonstration study and Appendix F, Section F.3.3, for a full discussion of the limitations of the seismic assessment methodology).

The 8% improvement in losses avoided is the result of the relatively strong seismic provisions in the 1994 UBC, widely adopted across the western states, and used as the comparison against the I-Code and similar codes. Had there been areas with no seismic codes in use prior to 2000, the losses avoided would be considerably larger. For example, for post and pier houses in parts of Hawaii (see Exhibit 6-1), the losses avoided as a result of I-Code (or similar building code) provisions are substantial, especially for the higher hazard areas of Hawaii County. The post and pier buildings are a unique case study in which custom damage functions applicable to an easily identifiable set of buildings are available; other seismic force-resisting system detailing enhancements have been added to the I-Codes since the 1994 UBC that cannot currently be directly modeled in the same way and have not been captured in this study (see Appendix F, Section F.3.3, for a more complete discussion of this study's limitations).

Table 6-8: Summary of Pre-I-Code and I-Code Average Annual Losses and Losses Avoided by State for the Six Western Seismic States

			Pre-I-Code AAL			I-Code(1) AAL			Losses Avoided			
State	Bldg Count	BRV ($M)	Bldg ($1,000)	Cont ($1,000)	Total ($1,000)	Bldg ($1,000)	Cont ($1,000)	Total ($1,000)	Bldg ($1,000)	Cont ($1,000)	Total ($1,000)	Per Bldg ($)
Alaska	41,055	$15,726	$9,501	$3,271	$12,772	$9,366	$3,244	$12,610	$135	$27	$162	$4
California	1,337,104	$914,309	$377,873	$160,098	$537,972	$351,817	$144,696	$496,513	$26,057	$15,402	$41,459	$31
Hawaii	54,162	$20,877	$14,174	$3,812	$17,986	$11,147	$3,822	$14,968	$3,027	–$10	$3,018	$56
Oregon	249,159	$95,020	$15,738	$5,921	$21,659	$14,675	$5,651	$20,327	$1,062	$269	$1,332	$5
Utah	252,990	$96,305	$18,566	$7,134	$25,701	$16,167	$6,359	$22,526	$2,400	$775	$3,175	$13
Washington	507,453	$261,950	$78,173	$31,722	$109,895	$69,642	$29,473	$99,115	$8,531	$2,249	$10,779	$21
Total(2)	**2,441,923**	**$1,404,187**	**$514,026**	**$211,957**	**$725,983**	**$472,814**	**$193,245**	**$666,059**	**$41,211**	**$18,712**	**$59,924**	**$25**

Bldg = building; BRV = building replacement value; Cont = contents, AAL = Average Annual Loss

(1) I-Code or similar code

(2) Due to rounding, some totals may not correspond to the sum of the separate figures.

As shown in Table 6-8, most of the losses avoided are attained in California ($41 million, representing 69% of the losses avoided in the six western seismic states), with Washington state contributing the next largest amount ($11 million or 18%). Losses avoided in Oregon are small relative to its percentage of the overall exposure; the state accounts for 2% of the total losses avoided but 7% of the exposed building value. The current Hazus analysis is limited to seven Design Levels with which to capture changes in code requirements. The smaller losses avoided in Oregon are the result of having a larger proportion of structures being assigned the same Hazus Design Level under both the pre-I-Code and I-Code (or similar) design due to relatively small changes in the code hazard maps; 91% of structures in Oregon have the same Design Level under both the pre-I-Code and I-Code, compared to 71% in California.

Hawaii also shows a net negative contents loss avoided, driven by the post and pier houses[7] (see Appendix F, Section F.3.2.3). Alaska produces the smallest losses avoided because the number of buildings in the database is small and because similar to Oregon, 87% of buildings have been assigned the same Hazus Design Level under both the pre-I-Code and I-Code (or similar), including 72% of the buildings that are assumed to have been built without the benefit of a building code (see Appendix F, Section F.1.6).

While the current study does not include a detailed assessment of the AAL and AALA in the eight NMSZ states (see Appendix F, Section F.5) and other seismic areas of the U.S., an extrapolation exercise was conducted to develop a rough estimate of potential losses avoided through I-Code (or similar code) adoption in the NMSZ. The extrapolation combined results of the current BCS Study, CoreLogic-derived post-2000 exposure data, and results from FEMA's most recent Hazus national AAL study (FEMA, 2017); details of the extrapolation methodology are provided in Appendix F, Section F.5.4.

Two versions of the extrapolation were produced to provide a range of results: one using Utah as the analog state (the state with the most similarities to the NMSZ states) and one using the six western seismic state average. Using the Utah-based extrapolation, the NMSZ states contributed an additional $6.1 million to the $59.9 million AALA estimated for the six western seismic states, bringing the total BCS AALA estimate for earthquake to $66 million. Using the six western seismic state average extrapolation, the revised BCS AALA estimate for earthquake would be slightly lower ($64.5 million). However, as noted in the limitations section (Appendix F, Section F.5.4.3), with detailed modeling of the NMSZ code history, post-2000 building inventory data, and construction practices, the net losses avoided could be significantly larger.

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[7] The custom damage functions for the post-2000 post and pier houses reflect the increased strength of the building. At a given hazard level, the strengthened building will experience decreased displacements but increased accelerations; contents damage depends on these increased accelerations, leading to larger content losses in the strengthened building.

6.3.2 Normalized Loss Ratios

The losses can also be stated in terms of normalized loss ratios expressing Average Annual Loss (and losses avoided) as a fraction of the building inventory replacement value, as given in Table 6-9. As shown, the net pre-I-Code normalized loss ratio is 517 ($AAL/$M exposed) for the six western seismic states overall, while the I-Code normalized loss ratio is 474 ($AAL/$M exposed). Normalized loss ratios are highest in Alaska (where some buildings were modeled as being built without the benefit of codes, so expected losses are high) and Hawaii (where the analysis included special handling for post and pier buildings; see Exhibit 6-1), followed by California and Washington.

Normalized Loss Ratios

Normalized loss ratios (AAL in $/building exposure in $M) are highest in Alaska and Hawaii; normalized loss avoided ratios (AALA in $/building exposure in $M) are highest in Hawaii (see Exhibit 6-1), California, and Washington

These values can be compared to the Annualized Earthquake Loss Ratios (AELRs) produced by the 2017 national earthquake AAL assessment conducted by FEMA (FEMA, 2017) using Hazus, included in the last column of Table 6-9 for comparison. The normalized loss ratios estimated in this study compare reasonably well with the AELRs from the FEMA (2017) study; the ratios in this study would be expected to be lower than the FEMA AELRs because (1) this study focused on the most recently constructed (and less vulnerable) part of the exposure and (2) this study included building and contents losses only (for consistency of results across hazards, see Appendix F, Section F.4.2), while the FEMA study included commercial inventory losses as well as income losses. Note that the Hawaii loss ratios that were produced in this study are larger than the FEMA AELR as a result of the custom modeling approach (see Exhibit 6-1).

Table 6-9: Summary of Pre-I-Code and I-Code Normalized AALs by State for the Six Western Seismic States

State	Pre-I-Code AAL/Building Exposure ($/$M)	I-Code AAL/Building Exposure ($/$M)	AALA/Building Exposure ($/$M)	FEMA 366 (2017) AELR ($/$M)
Alaska	812	802	10	1,058
California	588	543	45	971
Hawaii	862	717	145	708
Oregon	228	214	14	662
Utah	267	234	33	499
Washington	420	378	41	592
Total(1)	**517**	**474**	**43**	**870**

(1) Totals represent ratios of total amounts.

6.3.3 Negative Losses Avoided

Although at the state level, all losses avoided values (with the exception for contents for Hawaii) are positive, negative losses avoided values were estimated at the county level in several states (see Appendix A, Section A.1). Table 6-10 provides a count of buildings producing positive, negative, and no losses avoided, along with those losses. Overall, 75% of buildings included in the analysis produced losses but no losses avoided because their pre-I-Code and I-Code Design Levels are identical due to relatively small changes in the code hazard maps; this value is highest in Oregon (91%), Alaska (87%), and Washington (85%). Twenty-two percent of buildings produced positive losses avoided, and 2% produced negative losses avoided. California has the largest proportion of buildings producing negative losses avoided (3%), while Hawaii, Utah, and Washington each have less than 1%.

Primary Cause of Negative Losses Avoided

When buildings are located in areas with relatively small changes in code hazard maps between code editions, the buildings may have identical pre-I-Code and I-Code Design Levels. These buildings will produce losses but not losses avoided. In the current study, 75% of all buildings in the seismic analysis fell into this category. This proportion is highest in Oregon (91%), leading to low losses avoided in that state.

Table 6-10: Summary of Results by Losses Avoided Status for the Six Western Seismic States

		Number of Buildings			Losses Avoided ($1,000)		
State	**Building Count**	**With Positive LA**	**With Negative LA**	**With No LA**	**For Positive LA Buildings**	**For Negative LA Buildings**	**For No LA Buildings**
Alaska	41,055	4,754	467	35,834	$488	–$327	0
California	1,337,104	337,689	46,769	952,646	$44,278	–$2,819	0
Hawaii	54,162	32,546	72	21,544	$3,029	–$11	0
Oregon	249,159	20,190	2,091	226,878	$1,530	–$199	0
Utah	252,990	77,093	508	175,389	$3,229	–$54	0
Washington	507,453	75,561	2,375	429,517	$10,955	–$176	0
Total	**2,441,923**	**547,833**	**52,282**	**1,841,808**	**$63,510**	**–$3,587**	**0**

Negative losses avoided occur when the I-Code Design Level is lower than the pre-I-Code Design Level, resulting in estimated pre-I-Code losses that are smaller than estimated I-Code losses. Most negative losses avoided are due to the transition from zone-based hazards to contour-based hazards. Prior to the adoption of the IBC in the West, the UBC was used almost uniformly. The UBC defined hazard by zones (1, 2A, 2B, 3, and 4, with 4 being the highest), and within a zone, the design strength of a given building type did not change except for changes due to site soil conditions. The zone boundaries were not numerically determined based on expected shaking intensity but roughly set based on

Negative Losses Avoided

Negative losses avoided occur in 2% of the buildings that were analyzed and happen when the estimated pre-I-Code losses are smaller than estimated I-Code losses. Most negative losses avoided are due to the transition from zone-based hazards to contour-based hazards.

historical seismicity plus judgement and political influence. For example, most of California's Central Valley was UBC Zone 3.

From the first edition of the IBC in 2000, the IBC used contour maps of hazard, so within any existing UBC zone, a range of hazards would be stipulated under the IBC; from the low side, typically farthest from active faults, to the high side, typically nearest to active faults. The first contour maps produced for the 2000 IBC indicated that the old zones were conceptually correct but that boundaries, in general, were not accurate. In the 2000 IBC, although many sites in a given zone were required to have building strengths nearly the same as the previous UBC, some required more strength and some less. It was assumed that any strength reductions were scientifically justified and would produce more efficient building designs—designs that would meet the code intent but would have lower construction cost. In the current assessment, if more buildings in a county fell under reduced requirements than under increased requirements, the county could have negative losses avoided when going from the older codes to the IBC. This result is expected to occur predominantly in UBC Zone 3 or less; because in Zone 4, near active faults, the contour values of hazard generally increased.

The negative losses avoided issue is also influenced by the step functions inherent in Hazus fragilities; losses show a measurable change when a Design Level changes (e.g., from Moderate Code to High Code or the reverse). If the hazard parameters in a region are near a boundary, a small change in hazard from code to code can make a significant change in losses calculated. In contoured hazard mapping, such as used in the IBC, no such significant change in building strengths actually occur, but creating smooth transitions in building strengths in Hazus would be complex and beyond the scope of this study.

Exhibit 6-1: Hawaii

Small-single family residential construction in parts of Hawaii (the island counties of Hawaii and Maui) often use a post and pier-foundation system, where the first floor is typically elevated by 2 to 3 feet above grade, or greater, often to accommodate sloping sites. This type of construction is more vulnerable to damage than conventional wood-framed buildings on slab foundations, as demonstrated by the 2006 Kiholo Bay Earthquake when observed damage included "movement of piers, sliding or unseating of posts relative to piers, failure of braces and failure of other services" (FEMA, 2009b). After 2000, code-required improvements to continuous load paths made these structures more resistant to damage.

The performance of this building type has been studied extensively, and custom Hazus capacity and fragility curves have been developed (FEMA, 2012a). Custom capacity curves include one representing typical construction between 1972 and 1999, and one representing typical construction after 2000, including the code-required load path improvements.

For these post and pier buildings, the losses avoided as a percentage of pre-I-Code loss averages 25%, significantly higher than the 8% achieved in the seismic states overall. In addition, as shown in Table 6-11, the normalized AALA (i.e., the AALA, in dollars, divided by the building exposure value, in $million) averages 490 and more than 700 for Hawaii County. These values may be compared to the statewide average normalized AALAs (see Table 6-11) for the other five seismic states, which range from 10 (Alaska) to 45 (California). The results from this unique building type indicate that larger losses avoided would result in the West if seismic codes had not been in place for decades and comparisons were made between "no code" and "current code."

Table 6-11: Average Annual Loss and Losses Avoided Results for Post and Pier Construction in Hawaii

County	Building Count	Building Exposure Value ($M)	Pre-I-Code Total AAL ($1,000)	I-Code Total AAL ($1,000)	Total Loss Avoided ($1,000)	Normalized AALA ($LA/$M Exposed)
Hawaii	14,674	$2,996	$9,807	$7,683	$2,124	709
Maui	6,058	$1,484	$790	$720	$70	47
Total[(1)]	**20,732**	**$4,480**	**$10,596**	**$8,402**	**$2,194**	**490**

(1) Totals represent ratios of total amounts.

6.3.4 Losses by Occupancy

Table 6-12 provides a summary of AAL for the pre-I-Code and I-Code representations of the inventory, as well as a calculation of the losses avoided for all modeled buildings by general occupancy. For each state, analyses focused on the occupancies representing the bulk (approximately 98%) of the post-2000 construction, as measured by building area and exposure value (see Section 6.2.1). Accordingly, some states have limited exposure modeled for selected occupancies (i.e., industrial and other occupancies, such as agriculture, education, and government).

Overall, residential construction governed by the IRC, one- and two-family dwellings (Hazus Occupancy Classes RES1 and RES3A), account for 67% of BRV, 55% of both the pre-I-Code and I-Code (or similar code) AALs, and 53% of the losses avoided. For these structures, the loss avoided as a percentage of pre-I-Code loss averages 8%, driving the average. Other occupancies demonstrate larger relative losses avoided; commercial structures average 9.6% loss avoided as a percentage of pre-I-Code losses and industrial structures average 11.2%.

Average Losses Avoided

One- and two-family dwellings dominate the post-2000 exposure in the seismic states, representing 67% of building value. The average losses avoided for these buildings (8%) drive the overall average losses avoided.

Hawaii (see Exhibit 6-1) has the highest losses avoided as a percentage of pre-I-Code loss for one- and two-family dwellings (18.1%), while Utah has the largest non-residential losses avoided as a percent of pre-I-Code loss (22.7 and 28.7% for commercial and industrial structures, respectively). Alaska, with the smallest modeled exposure (robust CoreLogic data were available for just six boroughs), has negative losses avoided for non-residential construction, and 1.3% losses avoided over all occupancies. As noted previously, Oregon has relatively lower losses avoided due to having a larger proportion of structures being assigned the same Hazus Design Level under both the pre-I-Code and I-Code (or similar code) design.

Table 6-12: Summary of Average Annual Losses and Losses Avoided by General Occupancy and State for the Six Western Seismic States

State	Occupancy	Bldg Count	Bldg Area (Million SF)	BRV ($M)	CRV ($M)	Pre I-Code AAL ($1,000)	I-Code(1) AAL ($1,000)	Total LA ($1,000)	LA (% of Pre-I-Code AAL)	Average LA per Bldg ($)
Alaska	One- and Two-Family	38,449	71	$13,721	$6,861	$11,547	$11,072	$474	4.1%	$12
	Other RES	949	4	$664	$332	$349	$361	–$13	NR(2)	NR(2)
	COMM	1,425	6	$998	$966	$615	$786	–$171	NR(2)	NR(2)
	IND	232	2	$342	$514	$261	$390	–$129	NR(2)	NR(2)
	Other(3)	0	0	$0	$0	$0	$0	$0		
	Subtotal	**41,055**	**82**	**$15,726**	**$8,673**	**$12,772**	**$12,610**	**$162**	**1.3%**	**$4**
California	One- and Two-Family	1,239,711	3,017	$601,302	$300,651	$286,253	$261,597	$24,656	8.6%	$20
	Other RES	41,752	853	$167,827	$83,913	$109,830	$104,560	$5,270	4.8%	$126
	COMM	37,399	845	$128,888	$129,663	$123,467	$113,818	$9,649	7.8%	$258
	IND	4,924	98	$13,377	$20,066	$16,403	$14,726	$1,677	10.2%	$341
	Other	13,318	21	$2,915	$2,915	$2,018	$1,812	$207	10.2%	$16
	Subtotal	**1,337,104**	**4,835**	**$914,309**	**$537,208**	**$537,972**	**$496,513**	**$41,459**	**7.7%**	**$31**
Hawaii	One- and Two-Family	52,130	89	$17,370	$8,685	$15,197	$12,454	$2,743	18.1%	$53
	Other RES	394	2	$446	$223	$261	$244	$16	6.2%	$41
	COMM	1,638	17	$3,061	$3,061	$2,529	$2,270	$258	10.2%	$158
	IND	0	0	$0	$0	$0	$0	$0		
	Other	0	0	$0	$0	$0	$0	$0		
	Subtotal	**54,162**	**108**	**$20,877**	**$11,969**	**$17,986**	**$14,968**	**$3,018**	**16.8%**	**$56**
Oregon	One- and Two-Family	218,676	441	$67,322	$33,661	$11,542	$11,167	$374	3.2%	$2
	Other RES	7,163	64	$11,101	$5,550	$3,134	$2,833	$300	9.6%	$42
	COMM	5,083	70	$11,678	$11,678	$4,939	$4,443	$496	10.0%	$97
	IND	354	3	$387	$581	$219	$208	$11	4.8%	$30
	Other	17,883	34	$4,531	$4,531	$1,825	$1,674	$151	8.3%	$8
	Subtotal	**249,159**	**613**	**$95,020**	**$56,002**	**$21,659**	**$20,327**	**$1,332**	**6.1%**	**$5**

Table 6-13: Summary of Average Annual Losses and Losses Avoided by General Occupancy and State for the Six Western Seismic States (cont.)

State	Occupancy	Bldg Count	Bldg Area (Million SF)	BRV ($M)	CRV ($M)	Pre I-Code AAL ($1,000)	I-Code[1] AAL ($1,000)	Total LA ($1,000)	LA (% of Pre-I-Code AAL)	Average LA per Bldg ($)
Utah	One- and Two-Family	229,868	531	$74,623	$37,312	$17,504	$15,983	$1,521	8.7%	$7
	Other RES	13,079	67	$10,129	$5,065	$2,295	$1,991	$304	13.2%	$23
	COMM	6,615	70	$9,210	$9,210	$4,605	$3,560	$1,045	22.7%	$158
	IND	933	12	$1,293	$1,939	$761	$543	$219	28.7%	$234
	Other	2,495	7	$1,050	$1,050	$535	$448	$87	16.2%	$35
	Subtotal	**252,990**	**687**	**$96,305**	**$54,575**	**$25,701**	**$22,526**	**$3,175**	**12.4%**	**$13**
Washington	One- and Two-Family	467,326	1,026	$170,143	$85,071	$56,076	$54,288	$1,788	3.2%	$4
	Other RES	12,849	217	$39,509	$19,755	$18,696	$15,019	$3,677	19.7%	$286
	COMM	16,355	283	$41,423	$42,262	$28,247	$23,717	$4,530	16.0%	$277
	IND	720	21	$2,592	$3,888	$2,109	$1,677	$432	20.5%	$600
	Other	10,203	47	$8,283	$8,283	$4,766	$4,415	$352	7.4%	$34
	Subtotal	**507,453**	**1,594**	**$261,950**	**$159,259**	**$109,895**	**$99,115**	**$10,779**	**9.8%**	**$21**
Total	One- and Two-Family	2,246,160	5,174	$944,482	$472,241	$398,119	$366,561	$31,557	7.9%	$14
Total	Other RES	76,186	1,207	$229,676	$114,838	$134,564	$125,010	$9,554	7.1%	$125
Total	COMM	68,515	1,292	$195,258	$196,840	$164,402	$148,595	$15,807	9.6%	$231
Total	IND	7,163	137	$17,992	$26,988	$19,754	$17,544	$2,210	11.2%	$309
Total	Other	43,899	110	$16,779	$16,779	$9,145	$8,349	$796	8.7%	$18
	Total[4]	**2,441,923**	**7,920**	**$1,404,187**	**$827,686**	**$725,983**	**$666,059**	**$59,924**	**8.3%**	**$25**

(1) I-Code or similar code

(2) NR – Not Reported; percent losses avoided and average losses avoided per building are not reported for categories with negative losses avoided

(3) Other occupancies include agriculture, education, and government uses.

(4) Due to rounding, some totals may not correspond to the sum of the separate figures

CHAPTER 7
Findings

Chapter 7 develops findings, in terms of analysis of results to derive relevant information for planning and risk reduction decision making. It includes a comparison of the BCS data and losses avoided modeling results by hazards, geography and a range of demographic, cultural and code adoption history conditions across the nation. Meaningful comparisons are simpler to develop with a common information framework, which for the BCS Study was made possible by a national model building code: the I-Codes. Adoption of the I-Codes creates a common performance benchmark for states and local jurisdictions. The BCS Study results therefore demonstrate how and where I-Codes are adding definitive value.

This chapter uses maps and graphs to illustrate trends, opportunities, and challenges to increased code adoption related to realizing increased future savings through use of the I-Codes. The findings can help jurisdictions recognize the benefits of adopting I-Codes or updating to a newer edition as a means of lowering and diversifying community risk, among other things.

The first set of tables and maps (Section 7.1) is a comparison of BCS Study results for the three hazards. BCS Study data parameters and results are then applied to external demographic criteria such as average income, growth, and hazards exposure in Section 7.2. In the final section of this chapter (Section 7.3), the BCS Study results are extrapolated to estimate future savings. The current progress of hazard-resistant code adoption will continue to advance, compounding to continued and greater future average annual savings. The possibilities of achieving this include greater code adoption, growth in new construction, mitigation of older buildings, and more resilient community infrastructure, also influenced by the I-Codes.

The common thread of building codes evolve by evaluating the effects of natural disasters. The pattern is a progression of mitigations by disaster type and scale, informed by innovation and technology. The codes and regulations of the 1800s focused on fire and basic operational safety measures in reaction to events of the time; learning from recent events remains a focus of this current era of risk assessment and I-Code mitigation provisions for the three dominant hazards. The future is a race to create new rapidly evolving hazard-resistant provisions for dynamic hazards such as tornado, tsunami, wildfire, and climate change. These more complex hazards bring potential needs to mitigate multiple cascading adverse impacts such as tsunami or wildfire triggered geohazards (e.g., erosion, slope instability, debris flows). When viewed from the perspective of engineering and economic impacts, communities will conclude that they cannot afford *not* to invest in I-Codes as a minimum loss prevention—the subject of Chapter 8.

7.1 Comparison of Results by Hazard

Losses avoided vary by jurisdiction, based on their particular combination of hazard type and intensity, post-2000 construction count, square footage and replacement values, and blend of occupancies. A comparison of state losses avoided for all three hazards is presented in Table 7-1, which provides details of building counts and replacement value components contributing to each state's AALA.

7.1.1 Tabular Comparisons

As shown in Table 7-1, the top four states for AALA are Florida ($1 billion), Texas ($92 million), California ($88 million), and South Carolina ($86 million). Combined, these four states account for 80% of the total AALA for the U.S.

The next nine states are North Carolina, Alabama, New York, New Jersey, Mississippi, Arizona, Louisiana, Indiana, and Washington. The AALA for these states ranges from $44 million to $16 million. The AALA for each state is roughly one-fourth to one-half the AALA for Texas, California, and South Carolina (Florida is a much larger AALA). These nine states have moderate hazard intensity and high post-2000 building counts, high hazard intensity and moderate building counts, or low hazard intensity and high building counts.

The next 23 states have a fairly even distribution of AALA, from $7 million to $1.2 million AALA. However, the post-2000 building count is highly variable—from 20,000 to 800,000. The variability of building counts in relation to AALA is likely due to the variability in hazard intensity in most cases. Nevada, Colorado, Montana, Minnesota, and Illinois have high building counts but low AALA. Low AALA in these states is due to poor data coverage or lack of code adoption. These states have an opportunity to substantially increase their AALA by improving their data or updating code adoption.

Higher AALA is a reminder that states with multi-hazard risk have greater exposure and—in many cases, with older, weak building stock—greater vulnerability than states without multi-hazard risk. The distribution of AALA is more visible at county level (see Section 7.1.2).

Table 7-2 and Table 7-3 present AALA by occupancy in California and Florida, respectively, for all three hazards. Similar data for all 50 states is presented in Appendix A, Table A2-7. The occupancy distributions in California and Florida are fairly consistent, with residences accounting for about 85% of the post-2000 buildings. However, the AALA for these residences is less than 75% of the total AALA, which is less than anticipated. The disparity between the building count percentage and the AALA percentage is due to the larger AALA per commercial building.

Table 7-1: Average Annual Losses Avoided by State for Flood, Hurricane Wind, and Seismic Hazards

State	Post-2000 Bldg Count	Flood		Hurricane Wind		Seismic		Grand Total LA (x$1,000)
		Bldg Count Modeled(1)	Total LA (x$1,000)	Bldg Count Modeled(1)	Total LA (x$1,000)	Bldg Count Modeled(1)	Total LA (x$1,000)	
Florida	1,775,701	310,963	$168,634	1,666,348	$856,824			$1,025,457
Texas	2,539,003	95,287	$62,816	2,445,030	$28,751			$91,567
California	1,388,971	44,611	$46,890			1,337,104	$41,459	$88,349
South Carolina	429,580	38,363	$18,082	415,686	$67,648			$85,731
North Carolina	970,226	25,902	$9,682	870,586	$34,030			$43,712
Alabama	374,443	11,342	$4,498	351,452	$30,555			$35,053
New York	322,046	12,182	$24,183	296,846	$5,562			$29,745
New Jersey	244,922	36,932	$19,961	244,001	$7,368			$27,330
Mississippi	250,100	17,138	$5,337	218,613	$14,547			$19,884
Louisiana	108,918	19,517	$17,390	96,775	$1,195			$18,584
Arizona	751,206	11,355	$17,525					$17,525
Indiana	426,104	9,574	$16,315					$16,315
Washington	553,027	9,818	$5,448			507,453	$10,779	$16,227
Maryland	259,637	8,857	$6,100	255,542	$1,010			$7,111
Virginia	480,340	8,032	$5,032	463,801	$1,613			$6,646
Oregon	268,523	7,605	$5,126			249,159	$1,332	$6,457
Massachusetts	150,320	4,738	$1,004	149,853	$5,178			$6,182
Pennsylvania	404,483	4,766	$5,870	387,290	$3			$5,873
Georgia	923,382	14,247	$4,130	873,229	$1,258			$5,388
Minnesota	293,862	4,270	$5,350					$5,350
Hawaii	54,402	1,389	$54	54,402	$1,569	54,162	$3,018	$4,641
Illinois	261,798	2,998	$3,896					$3,896
Nebraska	127,463	4,342	$3,593					$3,593
Utah	256,631	2,064	$146			252,990	$3,175	$3,320
Idaho	183,208	5,153	$2,997					$2,997
Iowa	195,838	3,358	$2,879					$2,879
Kansas	168,676	3,024	$2,680					$2,680

Table 7-1: Average Annual Losses Avoided by State for Flood, Hurricane Wind, and Seismic Hazards (cont.)

		Flood		Hurricane Wind		Seismic		
State	**Post-2000 Bldg Count**	**Bldg Count Modeled(1)**	**Total LA (x$1,000)**	**Bldg Count Modeled(1)**	**Total LA (x$1,000)**	**Bldg Count Modeled(1)**	**Total LA (x$1,000)**	**Grand Total LA (x$1,000)**
Michigan	158,291	1,825	$2,539					$2,539
Colorado	458,424	3,691	$2,360					$2,360
Montana	109,585	1,818	$2,241					$2,241
Maine	49,312	1,439	$1,735	46,239	$6			$1,741
Rhode Island	20,743	1,118	$374	20,616	$1,354			$1,728
Nevada	353,102	4,037	$1,544					$1,544
Connecticut	85,483	3,120	$235	84,055	$1,247			$1,481
North Dakota	25,853	1,426	$1,407					$1,407
Delaware	77,264	4,587	$263	75,076	$967			$1,230
Tennessee	577,340	8,632	$987					$987
Oklahoma	331,732	4,464	$939					$939
Arkansas	222,661	5,305	$770					$770
Missouri	328,607	5,153	$665					$665
Ohio	531,592	7,488	$447					$447
Wisconsin	42,023	167	$403					$403
West Virginia	98,870	3,700	$268	96,366	$1			$268
New Mexico	108,382	2,283	$247					$247
Alaska	41,492	1,732	$69			41,055	$162	$231
Kentucky	192,388	2,984	$207					$207
District of Columbia	4,762	76	$190	4,762	$3			$193
South Dakota	40,665	686	$62					$62
Wyoming	58,827	719	$18					$18
Vermont	14,353	286	$10	12,405	$0			$10
New Hampshire	77,561	1,910	$6	71,294	$4			$9
Total	**18,172,122**	**786,473**	**$483,602**	**9,200,267**	**$1,060,692**	**2,441,923**	**$59,924**	**$1,604,218**

(1) All buildings with adequate data to model. Results include positive, neutral, and negative losses avoided

Table 7-2: Average Annual Losses Avoided by Occupancy for Flood and Seismic Hazards in California

State	Occupancy	Total Post-2000 Bldg Count	Flood		Seismic		Grand Total LA ($1,000)
			Bldg Count Modeled(1)	Total LA ($1,000)	Bldg Count Modeled(1)	Total LA ($1,000)	
California	Single-Family Dwellings	1,239,735	39,663	$35,421	1,239,711	$24,656	$60,077
	Other Residential	42,335	1,971	$2,805	41,752	$5,270	$8,075
	Commercial	39,171	1,445	$5,925	37,399	$9,649	$15,574
	Industrial	6,382	477	$1,796	4,924	$1,677	$3,473
	Other(2)	61,348	1,055	$943	13,318	$207	$1,149
	California Total	**1,388,971**	**44,611**	**$46,890**	**1,337,104**	**$41,459**	**$88,349**

(1) All buildings with adequate data to model. Results include positive, neutral, and negative losses avoided

(2) Other occupancies include agriculture, religion/non-profit, education, and government uses

Table 7-3: Average Annual Losses Avoided by Occupancy for Flood and Hurricane Wind in Florida

State	Occupancy	Total Post-2000 Bldg Count	Flood		Hurricane Wind		Grand Total LA ($1,000)
			Bldg Count Modeled(1)	Total LA ($1,000)	Bldg Count Modeled(1)	Total LA ($1,000)	
Florida	Single-Family Dwellings	1,503,287	278,960	$147,066	1,503,257	$526,978	$680,300
	Other Residential	52,449	14,854	$5,687	52,301	$103,303	$108,990
	Commercial	64,583	10,634	$11,430	64,229	$177,924	$189,354
	Industrial	2,770	353	$246	2,770	$4,833	$5,078
	Other(2)	152,612	6,162	$4,205	43,791	$43,796	$48,002
	Florida Total	**1,775,701**	**310,963**	**$168,634**	**1,666,348**	**$856,824**	**$1,025,457**

(1) All buildings with adequate data to model. Results include positive, neutral, and negative losses avoided

(2) Other occupancies include agriculture, religion/non-profit, education, and government uses

Also of note is that although Florida has roughly the same number of post-2000 residential structures as California, Florida has about 2.5 times the number of post-2000 agricultural, non-profit, and public buildings, which is the result of different growth patterns and demographics (see Section 7.2).

7.1.2 Mapped Comparisons

The BCS Study flood, hurricane wind, seismic, and combined AALA results are mapped by county in Figure 7-1 through Figure 7-4, respectively. These figures portray the spatially the hurricane wind and seismic hazard areas of high intensity and nationwide the areas with insufficient data to model, representing code adoption needs.

Figure 7-1 displays the flood hazard AALA by county for the U.S. The map shows higher AALA values generally toward the coastlines but areas with substantial AALA values scattered throughout the interior of the nation and a significant portion of the upper Midwest, owing to code advancements by lessons learned, such as after the catastrophic 2008 Midwest floods. Also of note are the significant number of counties that do not have sufficient data to model and the counties with no losses avoided, owing to limited flood provisions in building codes or other ordinances (usually residential). The map illustrates flood hazards are prevalent across the nation and communities shown in green where AALA's occur being proactive in reducing flood losses. However, it also illustrates that many communities have not adopted I-Codes and that there is room for improvement – where no AALA occurs or where data is insufficient.

Figure 7-2 displays the hurricane wind AALA by county for the U.S. The map shows a decrease in values moving inland from the coast. The trend in AALA values is generally associated with the I-Code maps of wind velocity contours shown in Section 5.2 and especially the severe WBDR (indicated on the Figure 7-2 map as "high wind hazard" areas). The map illustrates AALA I-Code benefits (green) for even communities located outside of high wind hazard areas, showing that inland communities should be encouraged to adopt I-Codes to reduce losses.

Figure 7-3 displays the seismic hazard AALA by county for the U.S. The map shows generally widespread losses avoided statewide, attributable to the history of early statewide code adoption. Alaska is the notable exception to this pattern, which is not surprising given the sparse population outside of the Anchorage and Juneau areas, precluding rural data being available to CoreLogic. Even in low-growth areas and those outside the hazard area, adopting I-Codes provides an opportunity to avoid losses, to encourage Alaska and others.

Figure 7-4 is a map of the AALA for the combined hazards. The map is somewhat difficult to interpret due to the inability to separate out individual hazards factors. Comparing Figure 7-4 with the data presented in Figure 7-1, some of the trends by states are very similar in losses avoided arising from code adoption, data quality, growth level, and hazard exposures.

Section 7.2 explores further the combined results, continuing at the county level with the introduction of demographic factors, to help clarify the results.

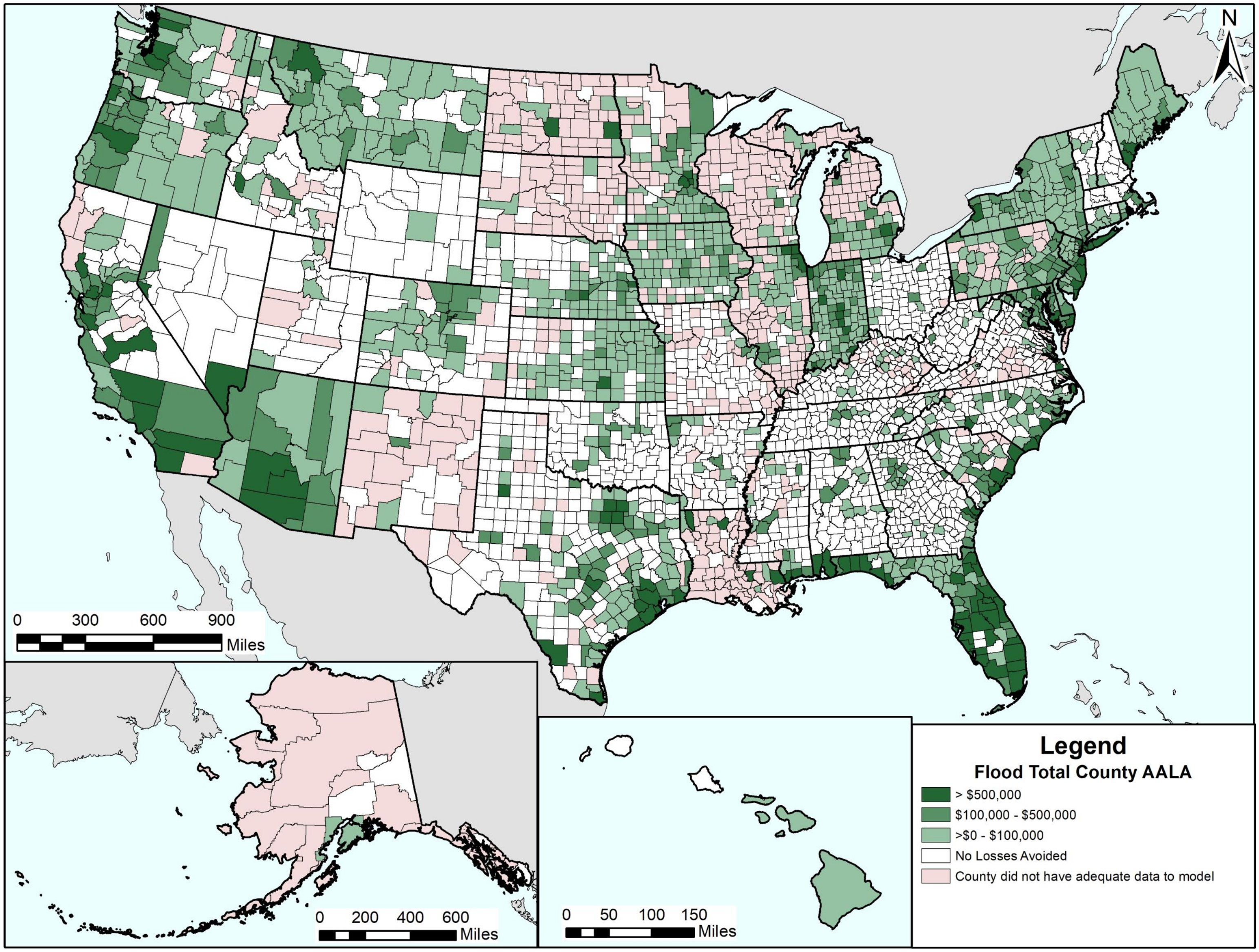

Figure 7-1: Total AALA by county for flood hazard analysis

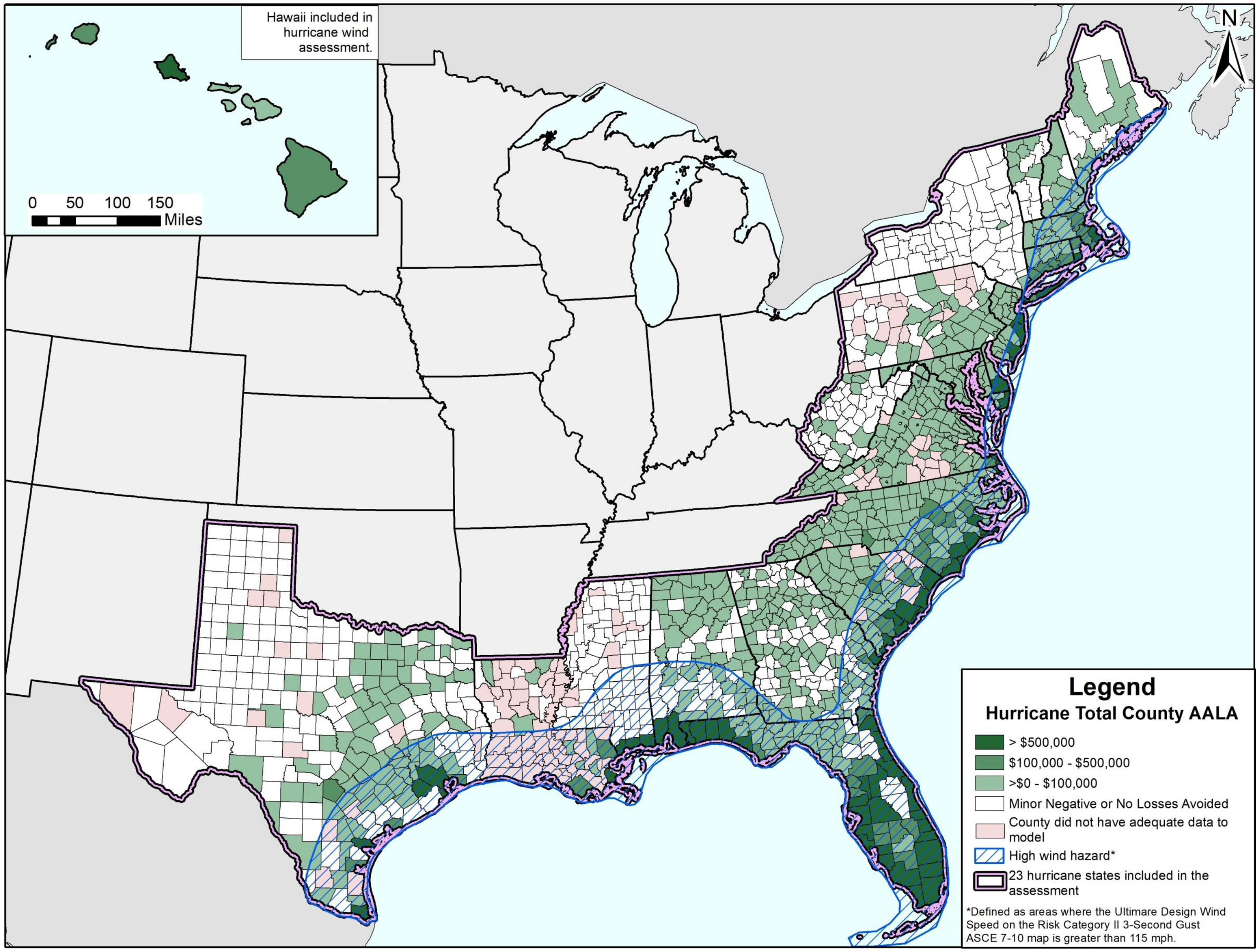

Figure 7-2: Total AALA by county for hurricane wind hazard analysis

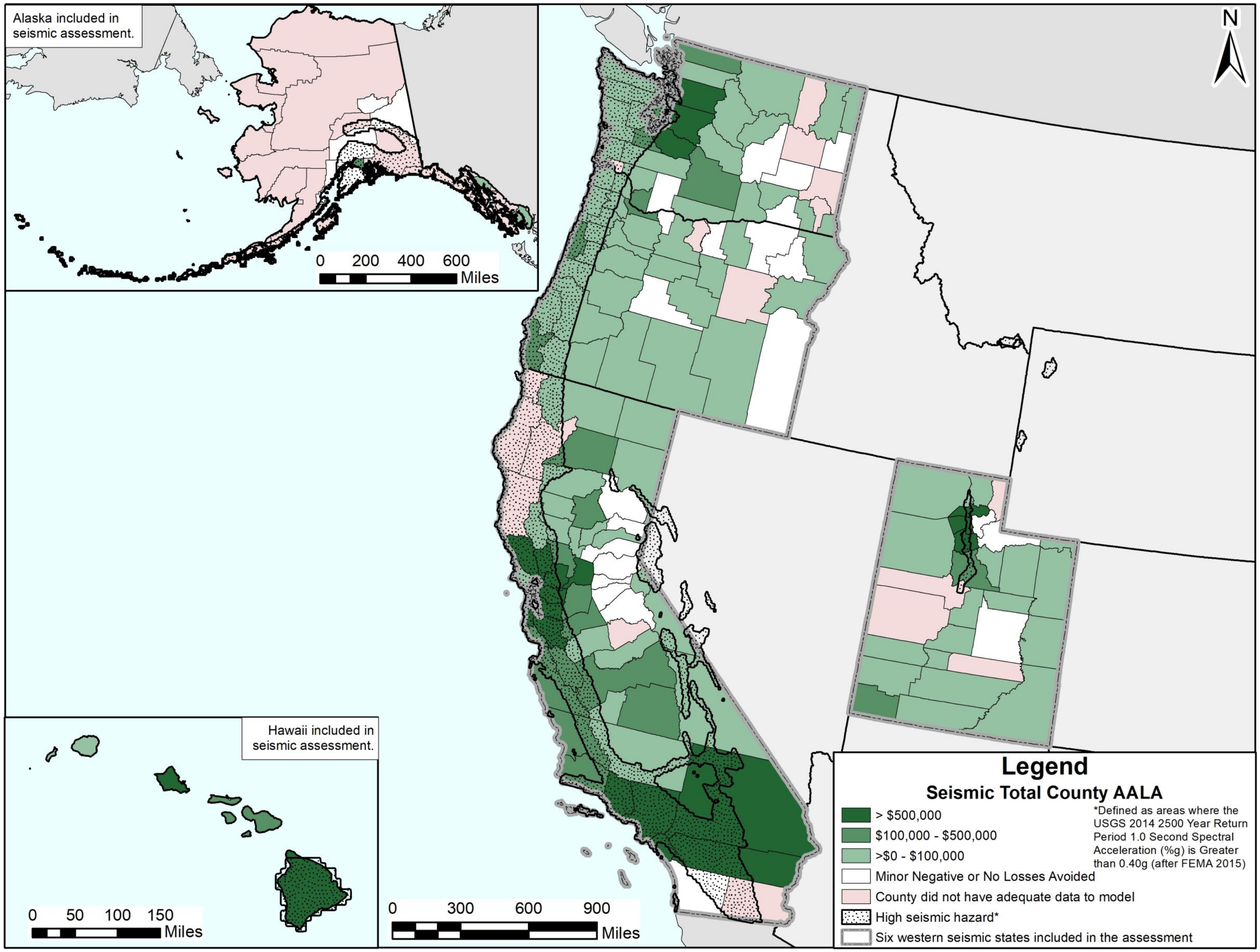

Figure 7-3: Total AALA by county for seismic hazard analysis

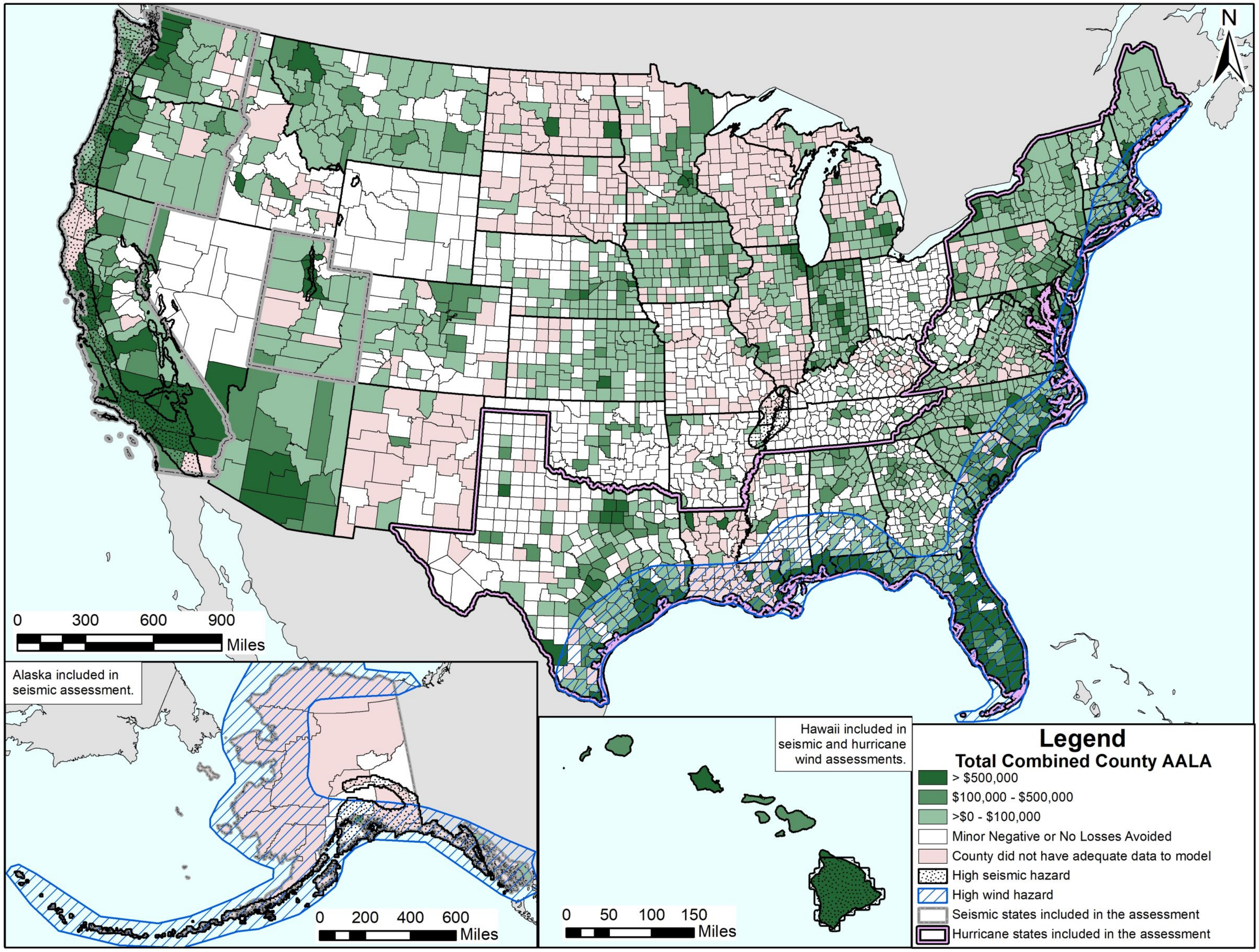

Figure 7-4: Total AALA by county for all hazard analyses combined

7.2 Comparison of Results by Demographics

The combined hazard AALA results by county can be understood from several perspectives by comparing trends among the demographic criteria of growth rates, occupancy patterns, and income. The BCS Study AALA derived from these three demographic factors illustrates achievements and the need to improve community resilience. The contrast between counties can be seen as an indicator of needs/opportunities and also as a reflection of a community's planning success (growth), risk attitude (building use patterns), and resources (income). This section presents maps of demographic queries of the BCS Study results database.

7.2.1 Hazard Level and Growth Rate

The opportunity for realizing the most significant I-Code-related AALA values arises from the intersection of large numbers of post-2000 buildings exposed to significant hazards. Therefore, the location of high flood, hurricane wind, and seismic hazard exposure provides a starting point for identifying high-yield opportunities where high building count growth rates are also occurring and where code adoption status has room for improvement. Figure 7-5 overlays high growth and high hazards geographies. Evaluating hazard, growth, and code status of the counties can help identify opportunities where I-Code adoption can provide high AALA. Applying this approach nationwide results in prioritizing counties (see Table 7-4).

This "opportunity index" approach to identifying high-yield-opportunity counties described above results in high AALAs per building, which are useful in a benefit-cost analysis (BCA) to determine the benefit-cost ratios (BCRs). For example, the *Natural Hazard Mitigation Saves: 2019 Report* has a BCR of up to 11 for buildings that were designed and constructed to the 2018 IBC (NIBS, 2019). The BCR would be calculated by dividing a cumulative AALA per-year benefit to a building over a 20- or 30-year finance period, divided by the "cost of code" dollar value at the time of construction, increased by inflation over the same finance period.

Because the BCS Study covers a nationwide distribution of hazard levels and building types, the BCR would vary widely. Reporting the unaggregated parcel level AALA applied to every structure would be unprecedented spatial data management of building data and would dilute the perception of savings by focusing on small individual AALA. As a method of determining the feasibility of specific mitigation projects, BCA has only limited application in the AALA focused BCS Study, which does not quantify all of the benefits or any of the costs. Therefore, applying BCRs to the granular parcel results would like AALA, dilute the perception of benefit, which would be especially pronounced in AALA for the average to low hazard area. Most BCR studies are focused on specific areas for projects, and additional work would need to portray credible county-specific BCRs nationwide using the AALA results. However, the BCS Study results in Table 7-4 appear to contain many counties with sufficiently high AALAs to corroborate the findings of BCRs of 11 reported in *Natural Hazard Mitigation Saves: 2019 Report* (NIBS, 2019).

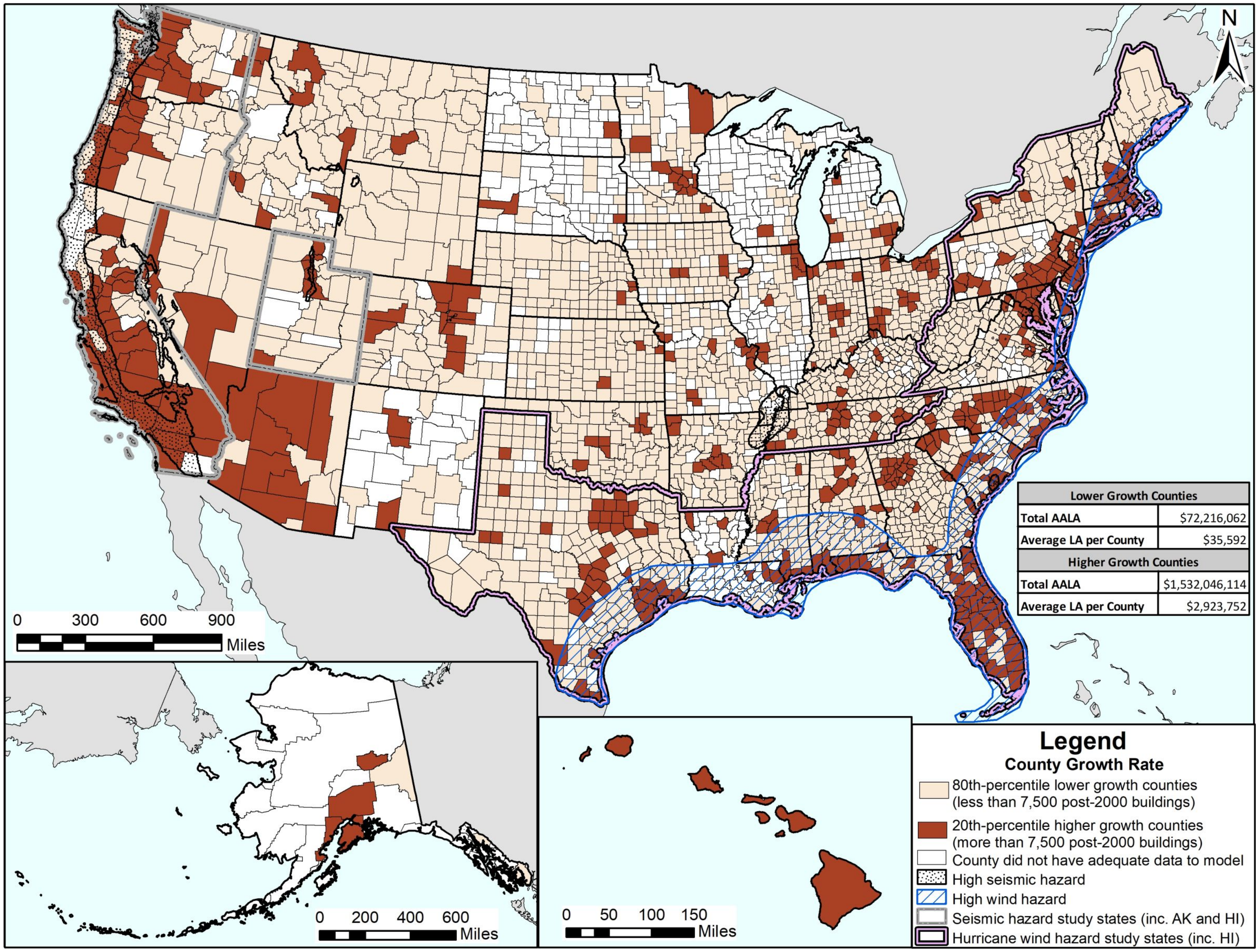

Figure 7-5: Lower-growth counties and higher-growth counties by count of post-2000 buildings

Table 7-4: Priority High Hazard, Higher Growth Counties with Limited I-Code Use

State	County	Post-2000 Count (Buildings)
Alabama	Marshall	7,797
	Cullman	7,873
Arizona	Yuma	21,579
Illinois	Tazewell	7,878
Kansas	Johnson	40,161
	Shawnee	7,671
Mississippi	DeSoto	24,284
	Madison	15,024
	Rankin	15,897
	Pearl River	7,764
	Hinds	11,150
	Lamar	8,662
	Lee	7,702
Missouri	Lincoln	9,819
	Christian	13,729
Montana	Flathead	18,482
	Missoula	9,574
	Gallatin	14,572
	Yellowstone	13,650
Nevada	Nye	7,928
North Dakota	Cass	11,745
Oklahoma	Wagoner	11,749
	Cleveland	30,689
	Canadian	22,117
	Comanche	8,068
	Rogers	13,371
	Oklahoma	51,999
South Dakota	Pennington	9,746
	Minnehaha	14,661
Texas	Ellis	24,136
	El Paso	66,976
	Henderson	8,515
	Brazoria	45,336
Texas	Guadalupe	31,621
	Hidalgo	88,884
	Montgomery	92,612
	Waller	7,530
	Webb	21,711
	Ector	9,104
	Brazos	21,215
	Cameron	37,286
	Fort Bend	124,527
	Smith	18,404
	Taylor	8,217
	Wise	10,591
	Hood	8,245
	Hunt	10,013
	Johnson	19,027
	Nueces	21,939
	Burnet	7,747
	Bastrop	12,032
	Grayson	12,275
	Hays	33,786
	Chambers	7,939
	Kaufman	20,138
	Liberty	8,504
	Midland	11,684
	Parker	20,075
	Randall	13,696
	Rockwall	17,747
	Wilson	8,352
	Kendall	8,145
	Bell	43,944
	Comal	24,895
	Harris	356,315
Wisconsin	Dane	9,324
	Kenosha	8,604
	Total	**1.75 million**

The 67 counties in this table (3% of counties nationwide) represent nearly 10% of the national post-2000 building count.

The hazard versus growth rates opportunity analysis in Figure 7-5 and Table 7-4 is an example of the BCS Study goal to incentivize communities to act by identifying which counties and areas of the country benefit through high AALAs from adopting I-Codes. Of equal importance to all communities and citizens is to identify additional or future I-Code savings opportunities. Smaller low-hazard or low-growth communities often have limited resources to respond to a natural disaster; for these communities especially, planning is not only to increase financial and economic benefit to the community but a necessity for maintaining critical functions of the community. A goal of the BCS Study is to support communities in developing their own forward-leaning goals for disaster risk reduction and community resilience, which starts with establishing goals in building performance.

7.2.2 Residential Opportunity

Because residential dwellings constitute about 85% of the building inventory (Figure 7-6), improvements to residential code adoption provide a significant opportunity in which a code enhancement or requirement applied to the inventory can produce a large effect. For example, as more states adopt the 2015 or later IRC, which requires a minimum 1 foot of freeboard for dwellings in the SFHA, it is anticipated that the AALA will continue to increase in high hazard areas. However, I-Code hazard resistance should also be encouraged in areas where the codes are not currently required, to better protect millions of families across the nation.

7.2.3 Income-Driven Opportunities

Given the dominance of residential dwellings in the nationwide building inventory, a logical way to help address affordable housing is to make the inventory hazard resilient, thereby extending the housing investment value for homeowners with limited resources to help absorb the acute shock of a disaster event. Building codes savings and safety for vulnerable populations should be an agenda item in discussions on affordable housing in communities across the U.S.

Figure 7-7 shows the median household income by county nationwide. By itself, the map does not show obvious correlations to code adoption or hazard intensity, or rate of post-2000 building counts. Figure 7-8 shows a comparison of median household income versus AALA dollars for all 2400+ counties nationwide. One conclusion of the broad scatter is that other factors are largely in play relating to community adoption of code requirements. The variability of a wide range of AALAs in lower incomes begs the question: why? Could it be some degree of value purchases or priorities of a portion of lower-income owners, such as sustainability-conscious younger professionals. Or some upward mobility of longtime lower income earners to seek resilient housing? At the county level, it is hard to distinguish ownership of low-income rental buildings from lower income homeowners. But the lack of a clear low-income trend raises the social question: Can resilient dwellings foster or attract resilient dwellers willing to pay a higher premium of their limited resources?

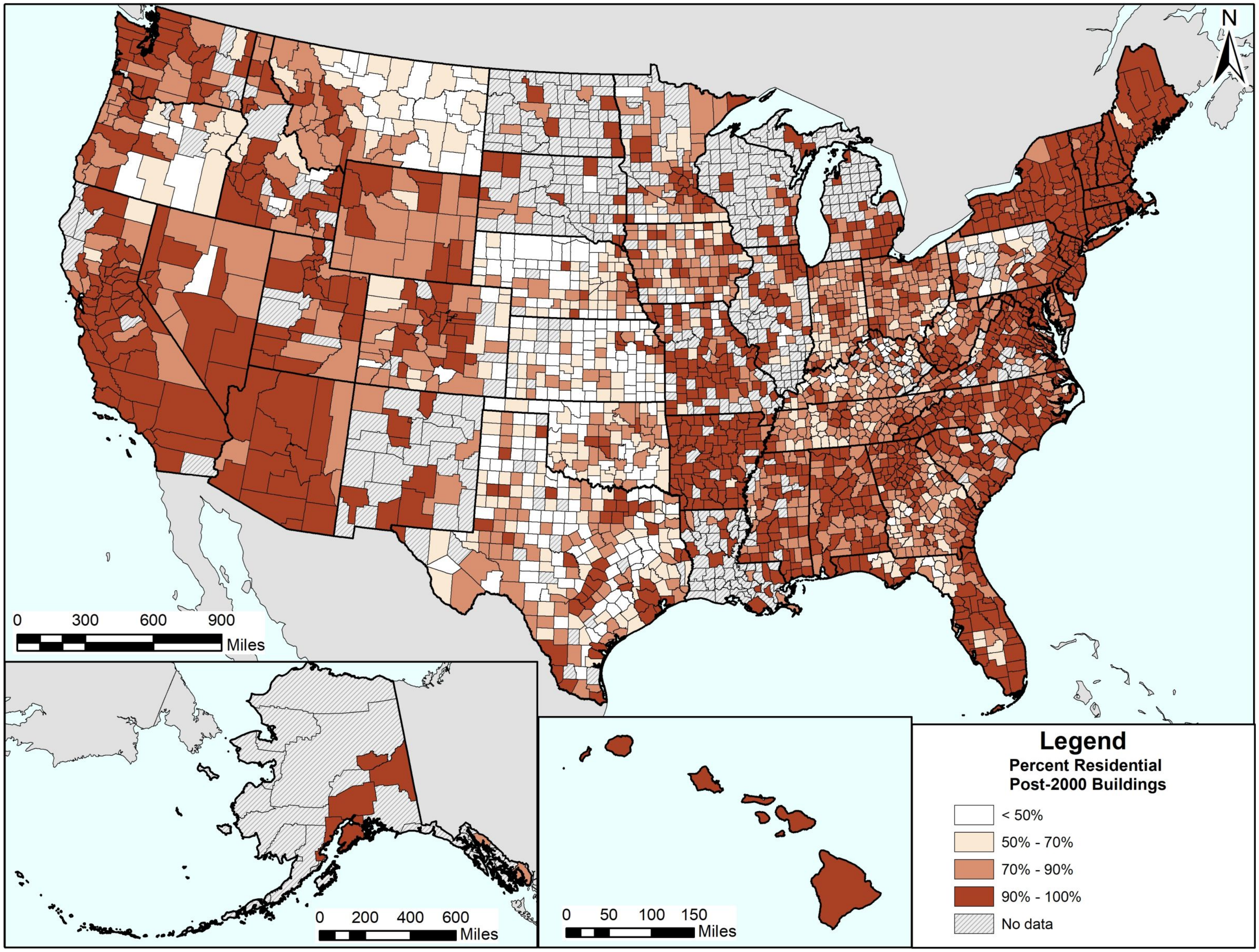

Figure 7-6: Percentage of residential post-2000 construction building counts by county

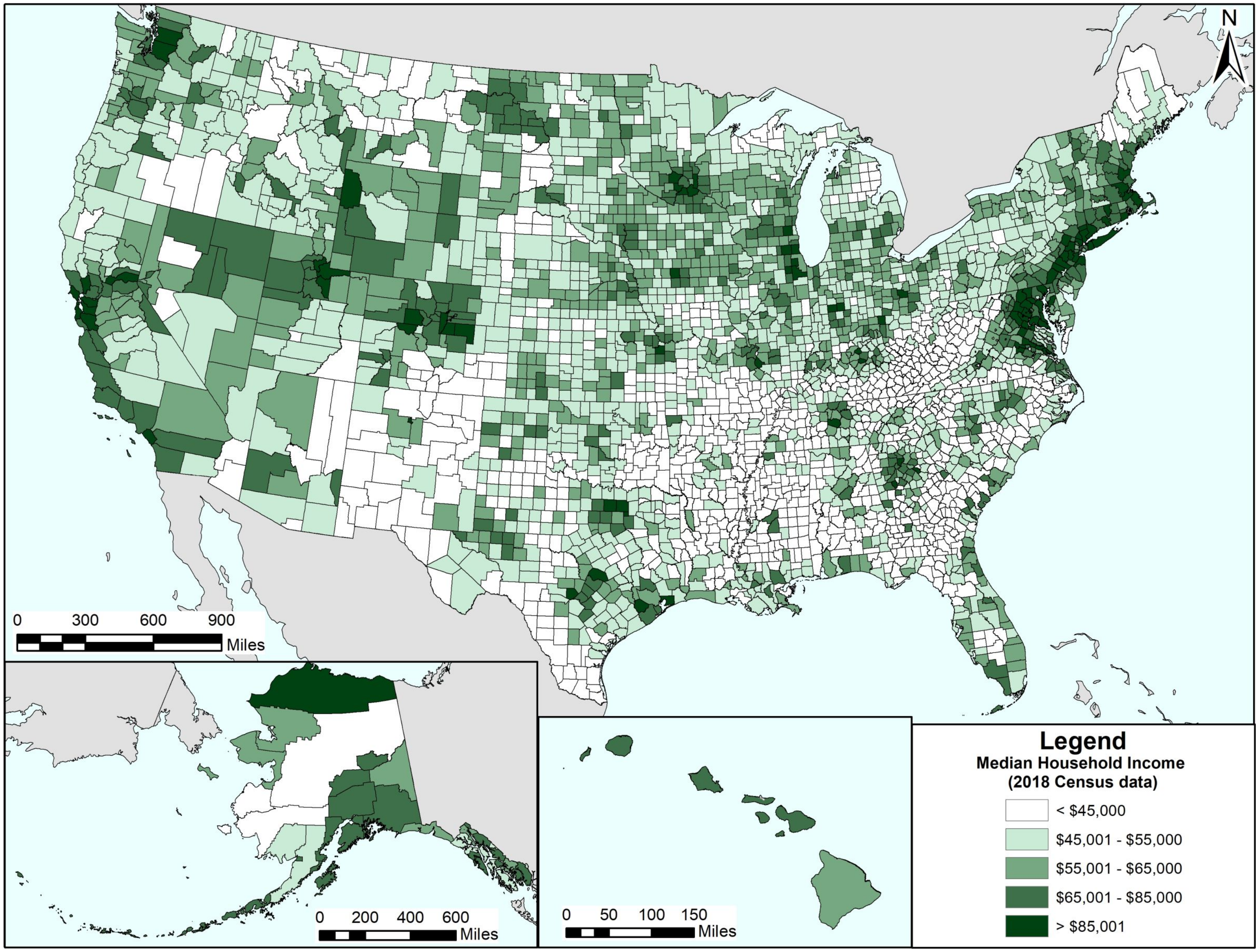

Figure 7-7: Median household income by county (U.S. Census Bureau, n.d.)

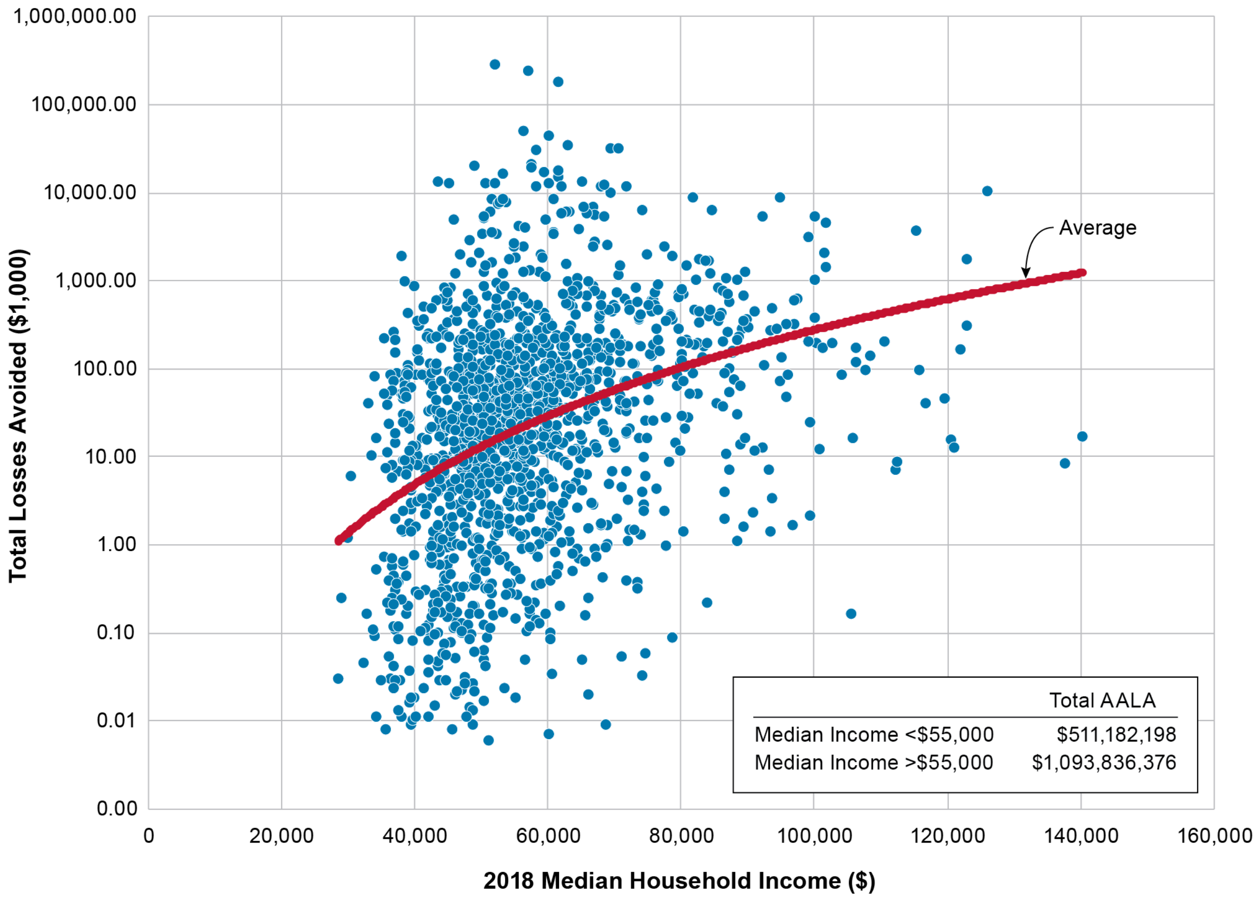

Figure 7-8: Median household income in dollars versus AALA dollars (building count in the inset table)

Another observation of the scatter plot is that median incomes above $80,000 have a lower-bound average AALA of about $1000, which is clearly higher than the AALA minimum of $10 at lower incomes. In considering the amount of lower AALA properties depicted, it remains a core message of the BCS Study that home safety and hazards resilience is needed by all. And all should seek the best building performance one can afford to develop the best community resilience for available resources.

7.3 Future AALA Estimates – Extrapolating Results

Although contrasts in losses avoided nationwide can be attributed to locally identifiable causes, the same holds true in identifying opportunities for communities of all sizes, exposure, and code status: there is opportunity to effectively focus limited resources to maximize benefits, specifically by adopting certain code mitigation measures that provide higher losses avoided.

7.3.1 I-Code AALA Growth in the Future

The evaluation of post-2000 construction is intended to provide insight for positively shaping the future. To this end, the BCS Study demonstrates that perpetuating the benefits of early adopters of I-Code (or similar) provisions may have produced lower current losses avoided (e.g., California seismic losses avoided) but that the compounded larger losses avoided over time are already accruing. Also considered in future postulations are decisions on new construction affecting the accrual of AALA such as planned useful life, portfolio changes (aging and retiring of buildings), changes in hazards, and population growth and economic trends driving community actions.

Many areas of uncertainty in estimating future AALA and I-Code–derived benefits include:

- What is the likely growth pattern—by geography, when the building is constructed, and hazard exposure—and what is the likely percentage of I-Code buildings in the future?
- How can we calibrate the BCS Study findings with actual past AAL for an event?
- What was not modeled by the BCS Study that could be modeled in future efforts?

The baseline future assessment is the compounding of current AALA values using the same average building rates (counts per year) from 2009 to 2016 setting the yearly increase. The $1.6 billion AALA modeled will follow the baseline trend expanded to 2040 to an AALA of $3.2 billion and $132 billion cumulative losses avoided. Alternatively, fitting a trendline through the modeled AALA data points results in an estimated AALA of $4.2 billion in 2040 and $171 billion cumulative losses avoided.

Other possibilities for “what-if” scenarios to extrapolate cumulative losses avoided are:

1. Increase in the percentage of new I-Code buildings increasing the annual count, compounding the AALA and yearly cumulative losses avoided. This could increase twofold because 50% of the post-2000 buildings are modeled I-Code buildings.
2. Increase in the number of mitigation projects to I-Code performance, which is a potential added fivefold increase in AALA counts per year at maturity because the 18 million post-2000 buildings are about 20% of the total building inventory.

Note that over the building life cycle, these magnitudes become dramatic, and current AALA represent the tip of the iceberg. These measures combined become an enduring financial underpinning, meaning a durable investment within the current $5 trillion value of 9 million post-2000 I-Code buildings modeled.

Growth rates affect potential savings as with other investments, as illustrated in Figure 7-9.

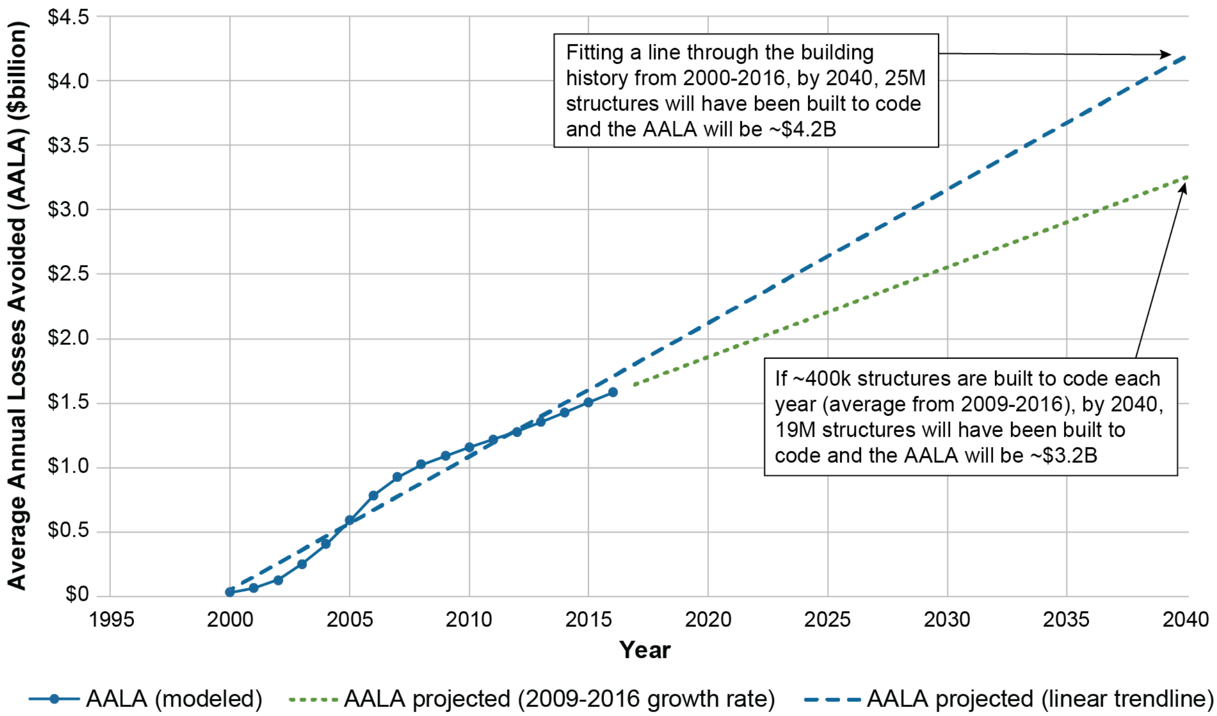

Figure 7-9: Potential variability in growth rates of the $1.6 billion AALA

7.3.2 I-Code AALA Extrapolation to the Whole Built Environment

Beyond the BCS AALA future growth of I-Code buildings, we can assess a full universe of "what if" boundary limits of particular I-Code growth opportunities developed to maturity.

The next 20 years will produce greater growth, with both a new high percentage of I-Code structures, and greater investment needs readily apparent from assessments of aging infrastructure, community investment needs, and economic growth forecasts. The code savings from one hazard become available capital funds for further reducing the next hazard. In this way, the losses avoided savings become an upward spiral of enduring reserves for weathering current hazards cycles, and as resources to develop effective solutions to potential additional types of hazards. A basic three-pronged universe of growth opportunity exists:

1. The remaining 50% of post-2000 buildings, if built to the I-Codes, would double the current AALA to $3.2 billion.
2. By the same rationale, the remaining 80% of pre-2000 buildings, if built to I-Codes, would increase AALA fivefold to about $15 billion AALA.
3. And community infrastructure, if roughly estimated to be about equal to the capital cost of buildings, and if it in entirety were developed to the I-Code performance levels, it would result in another $15 billion AALA at maturity. Infrastructure savings could further include:

- Community lifeline infrastructure resilience planning (NIST, 2015), which by intent aligns building code performance with infrastructure code performance for highest protections, targeted at critical system links (infrastructure) and nodes (buildings) to achieve hazards protection and recovery goals.
- Natural capital benefits of reduced disaster losses from design codes and other actions.

These numbers, compounded over a 20- or 30-year period, representing the total opportunity for I-Code savings and currently constituted, would produce staggering cumulative losses avoided of over a trillion dollars: a nationwide incentive to pursue I-Code savings.

In summary, the comparison of multi-hazard effects on community AALA, the growth rate, income, and future growth scenarios presents varied value-based possibilities. Emerging economic opportunities also include considerations that prompt extending code-derived AALA beyond buildings. Building on these concepts of affordable savings and future growth, the role of the community and economics of costs and benefits in advancing code savings is developed in Chapter 8.

CHAPTER 8

Advancing Community Benefits

Community benefits arising from losses avoided due to the adoption of I-Codes are abundant, and can have a ripple effect into the future, as do the benefits described in Chapter 7. This chapter describes the broader community benefits starting in terms of residential losses avoided, rippling outward to broader community assets, public health, and a resilient recovery, framed in terms of economic benefits.

Realization of community benefits requires both adoption of hazard-resistant building codes and communication of their benefits to influence community decisions. The communication needs presented in this chapter include economic considerations for code adoption, and outreach needs requiring engagement of all stakeholders.

8.1 Economic Considerations

Enacting building codes that specify certain construction requirements has long been used to reduce the susceptibility of buildings to damage during a natural hazard event. In *Natural Hazard Mitigation Saves: 2019 Report*, adopting the I-Codes was found to save $11 for every dollar invested (NIBS, 2019). Relative to 1990 standards, modern building codes add less than 1% to a home purchase price. These facts support the premise that adopting and enforcing building codes is among the most efficient ways to build a resilient society.

The cost of implementing building codes may be considered the price of the risk associated with developing in hazardous areas. A National Bureau of Economic Research study (Hino and Burke, 2020) found the price penalty for increased flood risk to be higher in states where sellers must disclose information about flood risk to potential buyers, suggesting that some properties may be overvalued when information about hazard risks is not provided. Not only can implementing I-Codes reduce the risk for property owners, it can also sustain the real estate market.

Although the effect of building code requirements in reducing damage is understood as it relates to individual buildings, evaluation of the overall effect of building code requirements on a community or region has been more limited. Community disaster resilience encompasses social, economic, institutional, physical, and natural domains.

I-Code adoption is also expected to generate federal savings, because less recovery spending would be required post-disaster. These savings can be reinvested in further mitigation, creating a positive circular economy.

The following subsections summarize some economic information gathered and evaluated in performing the AALA analysis in relation to developing potential uses and benefits of the analysis results.

8.1.1 Community Benefits Evaluation

Measuring the community benefits of adopting the I-Codes would start with developing a comprehensive list of I-Code provisions that are intended to reduce damage from natural hazards. This is a broader list of mitigation measures than those that were feasible for modeling in the BCS Study. The measures would be identified as being appropriate for either new construction or retrofit of existing structures.

Building on the Hazus modeling, communities could use conventional economics methods to prepare a more comprehensive analysis of adopting the I-Codes, characterizing the number of mitigation measures implemented with the I-Code (or similar code) in place. As in the BCS Study, the measures would be compared to actions had the I-Codes not been adopted, such as by using the prior level of code adoption as the comparative baseline.

The consequences of a natural hazard event can extend well beyond the direct economic losses that are typically estimated, to include secondary and tertiary effects. A primary effect can be defined as a direct impact from the natural disaster (e.g., damage to structures, contents, roads, utilities); a secondary effect is an indirect impact as a result of the primary effect (e.g., closure of businesses due to lack of power or inability of workers to get to work, injuries from clearing debris); and a tertiary effect is an induced impact as a result of the secondary effects (e.g., supply-chain impacts such as an assembly plant in another state being closed because supplies could not be provided by a factory that was damaged).

The concepts of secondary and tertiary effects are nuanced and often overlap. Secondary and tertiary impacts can be categorized as increased costs (e.g., indirect physical injuries and mental health), inefficient use of resources (e.g., additional efforts required to maintain business and facility operations), loss of services (e.g., public services that are no longer available or delayed), and losses to the labor market (e.g., labor forced to be idle or required to perform less productive tasks).

When the economic damages from secondary and tertiary effects occur because transfers to other firms or entities cannot be easily made, these are considered national losses. Therefore, the secondary and tertiary impacts are expected primarily during the natural disaster and initial response and recovery periods, when substitutes are not available. The impacts would likely diminish during the recovery period as substitutes are used and businesses become operational. Reducing the recovery period can limit the damages from secondary and tertiary effects.

The extent of the damage sustained by a community can affect its ability to recover following an event, and in some cases, its actual viability as a community. Although adoption of the I-Codes may not prevent all damage to buildings, any reduction in damage aids the recovery process. This is especially true when communities ensure that the I-Codes are applied to new structures, which tend to have the highest use value and greatest economic activity.

Figure 8-1 provides an example of these cascading effects and the potential benefits that can be realized through the damage reduction provided by the I-Codes.

I-Codes Accrue a Diverse Array of Benefits

- More lives saved and fewer people injured
- Fewer people displaced and for shorter periods
- More people can shelter-in-place while waiting for repairs
- Wellness increases, mental trauma is reduced
- Social and business disruption is reduced
- Infrastructure is more resilient because control buildings are not damaged
- Faster recovery from a disaster
- Reduced loss of income
- Enhanced market value of property
- Potential decrease of property insurance rates
- Continued public services, including to the vulnerable
- Accrued savings at the community level

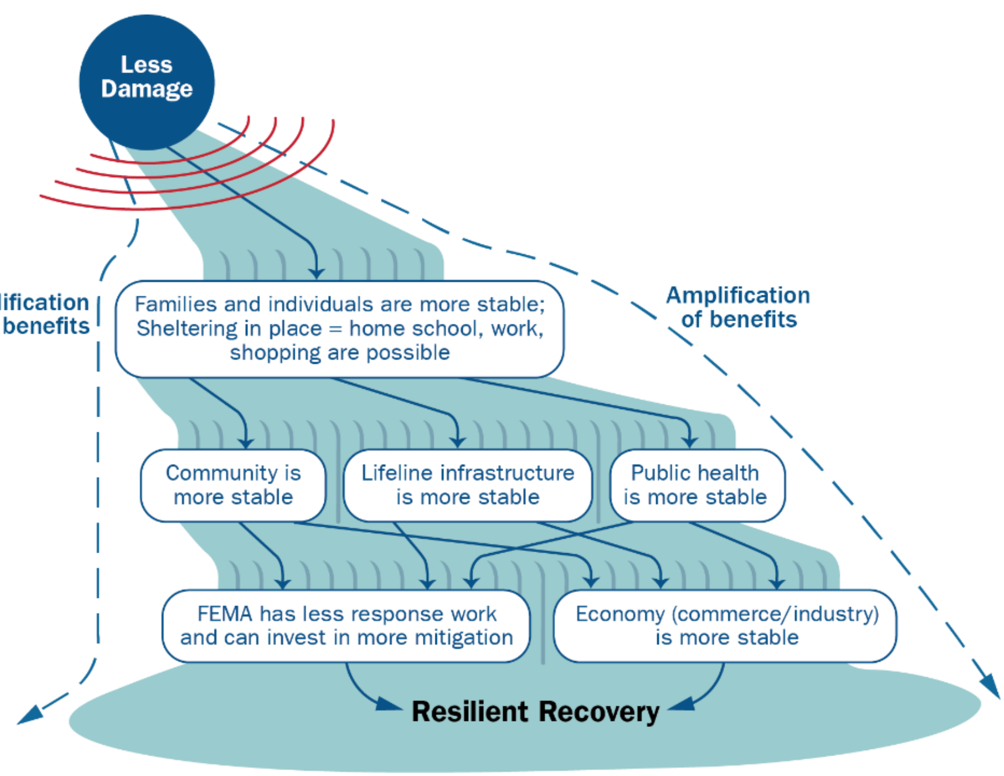

Figure 8-1: Cascading benefits of I-Codes

8.1.2 Rapid Recovery

Reduction in recovery time, although not modeled in the BCS losses avoided results, is an additional community benefit. As part of the BCS Study, this topic was evaluated by performing a literature review and discussions with industry groups and other experts.

In general, the amount of damage to a community from an event is related to the length of the recovery. Therefore, to provide a high-level scoping of the effect on a community's disaster recovery time, the percent reduction in damages from adopting the I-Codes can be a proxy in terms of reduced recovery time from specific events. Less damages means faster recovery and less impacts from secondary effects.

Logically, combining various increments of loss reductions and savings from adopting the I-Codes can be used to demonstrate the magnitude by which a community becomes less prone to damage, and more likely to recover quickly from an event. Communities may be able to use this information to obtain reduced insurance premiums or an increase in a bond rating. Although this type of evaluation may not be specific to a given structure, the results may provide an indication of the increased resilience of the community.

8.2 Outreach and Effective Communication

The BCS Study involved input from numerous stakeholders associated with data development and interested parties who may use the results. The combination of the current widespread usage and familiarity with both the I-Codes and the Hazus software provides an opportunity to engage the attention of a large audience in presenting the BCS Study findings as part of a process for risk-based community mitigation and resilience. Results presented in a common format like the BCS Study provide for consistent fact-driven outreach.

FEMA's Building Science Branch can work with its partner organization, Federal Alliance for Safe Homes (FLASH), to create attractive and effective messaging, mass broadcast, and other public relations aspects of outreach.

Work prepared by FLASH and other partner organizations will require coordination with the BCS team to provide technical content and ensure the accuracy of materials prepared by outreach partners and contractors.

This BCS Study identifies a range of relevant accessible data sources and processes, as well as solutions to further fill identified data gaps moving forward. The database serves as a baseline resource that can be dynamically modified for other potential preparedness and mitigation uses and research, including local, state, regional, and nationwide applications, and complementary studies such as *Natural Hazard Mitigation Saves: 2019 Report* (NIBS, 2019).

8.3 Portfolio of Supported Elements and Programs

The results of the BCS Study support the efforts of FEMA and its partners that address disaster risk reduction and adoption of hazard-resistant building codes. These elements and programs include:

- FEMA Strategic Plan, Objective 1.1 – FEMA's Strategic Plan provides a framework of goals and objective to strengthen the agency's mission to help people before, during, and after disasters. Objective 1.1 is to "incentivize investments that reduce risk, including pre-disaster mitigation, and [to] reduce disaster costs at all levels." The Strategic Plan acknowledges that disaster resilience starts with building codes (https://www.fema.gov/about/mission).
- FEMA Administrators Planning Guidance – This annual planning guidance put out by the FEMA Administrator to FEMA employees outlines priorities for resource and policy decisions with a focus on selected Strategic Plan objectives.
- FEMA National Mitigation Investment Strategy Recommendation 3.1 – The National Mitigation Investment Strategy is a single national strategy for advancing investment in mitigation to reduce natural hazard risks and increase resilience to natural hazards. Recommendation 3.1 is to "encourage communities to adopt and enforce up-to-date building codes." The Investment Strategy outlines actions that the Federal Government and its nonfederal partners can take in support of its recommendations (https://www.fema.gov/media-library-data/1565706308412-19739d7deeca639415cc76c681cee531/NationalMitigationInvestmentStrategy.pdf)
- FEMA Building Codes Strategy (under development) – This agency-wide strategy will advance the outreach, training, education, development, adoption, and enforcement of hazard-resistant building codes across FEMA programs.
- FEMA Community Rating System (CRS) – CRS incentivizes communities that implement floodplain management programs that exceed the NFIP minimum requirements. CRS requires certain BCEGS ratings, which reflect code adoption and enforcement, as prerequisites for reaching certain class levels (level 1 has the highest discount, level 10 has the lowest). Additionally, having 1 foot of freeboard for residential dwellings will soon be a prerequisite for class 8 (https://crsresources.org/manual/)
- FEMA Building Resilience Infrastructure and Communities (BRIC) Program – This new grant program includes eligible building code adoption and enforcement activities that evaluate, enhance, or develop codes and workforce training (https://www.fema.gov/grants/mitigation/building-resilient-infrastructure-communities)
- FEMA's National Risk Index – The National Risk Index identifies areas of the United States that offer a high return on mitigation investment. The index is based on hazard-specific variables, social vulnerability, and resilience.

(https://www.napsgfoundation.org/wp-content/uploads/2018/12/JRozelle_National-Risk-Index_20181204.pdf)

- No Code. No Confidence. (InspectToProtect.org) by FLASH – This interactive outreach tool is intended to raise citizens awareness of their residential code (https://inspecttoprotect.org/)
- FEMA's Building Code Assessment Tool – This detailed interactive map is intended for use by FEMA and states, and shows counties at risk, by hazard, and whether that county has adopted an up-to-date hazard resistant code for that specific hazard without weakening the code (http://geo.stantec.com/National_BCATS_Portal/viewer/)
- Time and Motion Studies:[8] Part of FEMA's StrongHomes project that compares actual construction costs (materials and labor) for homes built to building codes versus homes built to resilient standards such as FORTIFIED. The study is expected to be completed in 2021.
- Natural Hazard Mitigation Saves by NIBS – This benefit-cost analysis estimates benefit-cost ratios for various types of mitigation and perils. Adoption of hazard-resistant building codes is included in the study (https://www.nibs.org/page/mitigationsaves)
- Other studies: See FEMA's building science website (https://www.fema.gov/emergency-managers/risk-management/building-science)

8 Eric Vaughn, Executive Vice President, Federal Alliance for Safe Homes, email communication, July 28, 2020.

CHAPTER 9

Conclusions and Actions for Resilience

The results of the national BCS Study, which used the 50 U.S. states and Washington, DC as the study area, provide a strong incentive for states and communities nationwide to adopt modern hazard-resistant I-Codes. The methodology presented in this report has numerous strengths in organizing multiple building and hazard data sources, creating a first-generation nationwide model of actual buildings built to specific codes to develop the economic data validating tremendous benefits of building code provisions in reducing losses due to damage from natural hazards. The overarching conclusion is clear: adopting and enforcing the I-Codes avoids losses and saves money. In light of this evidence, communities can save money while making the right choice to increase public safety and community resilience.

It is anticipated that these findings will generate fresh state and local interest in pursuing savings and benefits through adoption of the I-Codes. A sustained commitment and strong advocacy for the codes from state and local officials with the public can result in overwhelming support for change.

Compounding Benefits of I-Codes

The compounding benefits of the modeled post-2000 I-Code construction resulting in $1.6 billion AALA will compound in the future assuming the same continued new building growth rate of the past 20 years, to become $3.2 billion AALA in 2040, with a cumulative losses avoided of $132 billion.

9.1 Conclusions of National Building Code Saves Study

Nationwide results demonstrate massive I-Codes savings from compounding value of reduced losses, which can in turn be reinvested into mitigations or other risk reduction measures, creating a local circular economic stimulus for avoiding losses to buildings from flooding, hurricane winds, and earthquakes. The key conclusions in the National BCS Study confirm that:

1. Adoption of modern I-Code brings compelling economic benefits and cost savings for all states and communities.
2. Those that have adopted I-Codes (and continue to adopt the latest updated editions) can avoid billions of dollars in annual losses.
3. Communities in low and moderate hazard areas benefit from combined saving of multi-hazard provisions in the I-Codes, including reduced damage from other hazards by generally strengthened and more durable buildings. Accumulated code savings in small

communities can proportionally still make the difference between a debilitating disaster and a resilient recovery.

4. Parcel data modeling of real buildings using big data methods effectively evaluates impacts to specific community conditions useful for local planning, yet rolls up easily to national results. This allows for timely monitoring of progress and encouragement of savings opportunities to communities small and large alike.

The results of the nationwide study confirm the BCS Study hypothesis—that significant financial and community resilience benefits are being realized by communities that have been proactive in adopting, updating, and enforcing the I-Codes. In addition to reducing physical damage, adopting I-Codes has benefits that include reduced economic impacts, such as lost rent and relocation costs, and reduced indirect disaster costs (lost productivity and impacts on health, education, the environment, social well-being, supply-chain, and financial health of the community). Although the BCS Study does not model these impacts or indirect cost savings, they compound the overall savings of adopting the I-Codes. These types of savings have been researched via the *Natural Hazard Mitigation Saves: 2019 Report* (NIBS, 2019).

9.2 Next Steps: Actions for Resilience

It is extremely difficult to create and sustain change, even with facts and proof in hand. However, the expertise that was leveraged to develop and implement the BCS Study was engaged with the goal that the study could have a profound, positive effect on the cause of building codes, and thereby sustain change nationwide. By fostering an understanding of the benefits, the study can help and encourage states and communities to adopt the I-Codes. The best opportunity a community has to reduce losses is to appeal to the public to improve the disaster resistance of their homes.

Homeowner I-Code Support

Communicating direct messages to homeowners can help win support for modern I-Codes. Messaging may include:

- Are you willing to live in a structure without a building code?
- Will your home be able to serve you during and after a disaster as shelter, schooling, an office, recreation center, and personal development activities? What is the cost to obtain these services elsewhere?
- Would you consider that even the most vulnerable deserve affordable safety? It is for all.

9.2.1 Residential Resilience

Extensive capital is accumulated through a community's residential building inventory, diversified by resources of the owners and financing institutions. The cumulative capacity far exceeds the capacity of local governments. Change toward realizing savings in residential construction across a community is achieved by advancing building code adoption in steps that can be accommodated with community resources both large and small, growing and reticent, starting with the IBC or IRC, and focusing on priority hazards and local building vulnerabilities.

9.2.2 Community Strengthening: The Final Case for Code Benefits

Key actions for building code adoption include the dominant residential code savings opportunity. Using BCS Study results and findings requires compelling key messages. The BCS Study findings can encourage states and communities to adopt I-Codes by communicating compelling benefits of reduced losses, and influence building a culture of community-wide resilience.

> **Motivating Local Change**
>
> Motivations for local change always tie into local stories somehow. When working to advance code adoption, proponents may want to remember that:
>
> - Historical disasters bring real-life motivation
> - Code changes and adoption can be influenced by community support
> - People respond to sustained advocacy
> - It helps to explain the steps of what happens when codes are adopted, how editions change—establishing enforcement programs removes the fear of change.

With the release of the BCS Study, FEMA plans to execute a multi-year communication and outreach strategy for communities. The strategy is being designed to ensure that the findings and insights are shared with the decision-makers and thought-leaders in communities throughout the United States, as well as taxpayers across the country who bear the accelerating cost of billion-dollar disasters. The need to better prepare people for disasters includes adopting the I-Codes in high opportunity communities, updating to the current I-Code editions in mature code communities, and expand the suite of I-Code products to fit areas of growth. The message to small communities is that the best way to reduce their disaster exposure profile is to grow their way into a more diverse and modern code community. A stagnant community has even fewer resources to cope with an event.

For all of the I-Code adoption progress that is documented in this BCS Study, an increased effort and sense of urgency are needed as an enduring commitment to advocate for increased building code adoption through increased awareness of the compelling savings and benefits. Building codes need to be advocated to officials and decision-makers as the socially critical elements of communities they are. In that regard, I-Codes can become recognized and branded along with things like Energy Star, LEED, behavior-based safety, and other successful industry value propositions that increase safety while they save money. The universal appeal of the BCS Study is the benefit to homeowners, businesses, government, and the design industry. The modern codes are a success of technology to improve life—in this case by delivering ever-increasing, affordable, safe, resilient buildings for all.

Closure: Reducing physical damage is only a part of the benefits associated with adoption of I-Codes. The compounding financial benefits and many other cascading community benefits deserve strong public communication and advocacy. Attached is the BCS graphical brochure entitled "Protecting Communities and Saving Money: The Case for Adopting Building Codes, which sets forth these benefits and call for action to address the natural disaster risks of our time.

CHAPTER 10

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CHAPTER 11

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