FEMA Benefit-Cost Analysis Re-engineering (BCAR)

Hurricane Wind Module Methodology Report

Version 4.5

May 2009

Contents

Purpose

This report is provided for use by the Federal Emergency Management Agency (FEMA) Technical Advisory Group (TAG) to review and approve the recommended methodology for the reengineering of the FEMA Hurricane Wind Benefit-Cost Analysis (BCA) Module. The goal is to develop methodologies that provide more accurate BCA based on well-defined scientific and engineering principles that accurately represent structure performance and hazard data.

Problem Statement

The following is a summary of the major assumptions and equations related to the Hurricane Wind Module that significantly affect the typical analysis. Problem statements are defined for those components that need to be addressed, as identified in the Benefit-Cost Analysis Re-engineering (BCAR) Methodology Update List or during the September 2007 BCAR TAG Meeting.

Overview

The benefits of a hazard mitigation project are the future losses prevented or reduced by the project. The benefits counted in a BCA are the present value (in dollars) of the sum of the expected annual avoided damages over the project useful life. A BCA takes into account:

- Probabilities of the wind hazards
- Building type and damages
- Contents, displacement, and loss of function
- Useful lifetime of the mitigation project
- Time value of money (the discount rate)

The benefits of a hurricane wind hazard mitigation project are the net present value of the total expected annual benefits over the useful lifetime of the hazard mitigation project at the annual discount rate.

$$B = AB\left[\frac{1-(1+r)^{-T}}{r}\right]$$

Where:

B is the benefits of the hazard mitigation project.

AB is the total expected annual benefits of the hazard mitigation project.

r is the annual discount rate used to determine the "Net Present Value" of benefits. For FEMA-funded projects, the rate is set by the Office of Management and Budget (OMB).

T is the estimated amount of time (in years) that the mitigation action will be effective.

To determine the expected annual benefits, the module multiplies the expected annual damages and the effectiveness of the mitigation measure. Expected annual benefits are calculated separately before and after the mitigation measure for each storm class from 0 to 5:

$$EAB = (EAD_{BeforeMitigation})(EFF)$$

Where:

EAB is the expected annual benefit.

$\mathbf{EAD_{BeforeMitigation}}$ is the expected annual damages before mitigation.

EFF is the effectiveness of the mitigation measure in reducing expected damage from a hurricane winds of a given storm class.

Equivalently, the expected annual net benefit is the difference between expected annual damages before and after mitigation. Expected annual benefits are calculated for each storm class from 0 to 5.

$$EAB = EAD_{Before Mitigation} - EAD_{After\ Mitigation}$$

Where:

EAB is the expected annual net benefit.

$\mathbf{EAD_{Before\ Mitigation}}$ is the expected annual damages before mitigation.

$\mathbf{EAD_{After\ Mitigation}}$ is the expected annual damages after mitigation.

To determine the expected annual damages, the module multiplies the scenario damages and the expected annual number of hurricane winds of a given storm class.

Expected annual damages are calculated separately before and after the mitigation measure for each storm class from 0 to 5:

$$EAD = (SCD)(EAE)$$

Where:

EAD is the expected annual damages.

SCD is the total Scenario Damages.

EAE is the expected annual number of hurricane winds of a given storm class.

The total expected annual benefits of a hurricane wind hazard mitigation project are the expected annual benefits summed over the full range of damaging hurricane winds considered (i.e., 0 to 5):

$$AB = \sum_{SC=0}^{5} EAB$$

Where:

AB is the total expected annual benefit of a hurricane wind hazard mitigation project.

SC is the range of hurricane storm classes (i.e., wind speeds) considered.

0 is the minimum damaging storm class considered in the Benefit-Cost Program.

5 is the maximum storm class considered in the Benefit-Cost Program.

EAB is the expected annual benefits from each storm class being considered.

Hurricane Wind Hazards

Probability of Hurricane Event

In the technical guidance that accompanies the FEMA Hurricane-Wind BCA Module, users are currently directed to a reference to determine site-specific wind-hazard data. This reference is the December 1985 "Coastal Engineering Technical Note" (CETN-I- 36) that was prepared by the U.S. Army Corps of Engineers' Coastal Engineering Research Center. This technical note bases all guidance for wind speed selection at a particular site and its associated return periods on work performed by Batts et al. (1980).

The Hurricane hazards research by Batts et al. that provide winds speeds for the 10-, 25, 50-, 100-, 500-, and 2000-year return periods for given locations for the Gulf and Atlantic coasts (Figure 1 and Table 1). Though there have been recent updates to the wind hazard data in the July 2006 Benefit-Cost (BC) Module, the technical approach described above is still currently referenced in the Technical BC Guidance and is the most widely used and known by most BC hurricane wind users. The BC Module uses the wind data in the input fields as shown below in Table 2- Wind Hazard.

Figure 1:
Locator Map for Mileposts on the Gulf and Atlantic Coasts

CETN-I-36
12/85

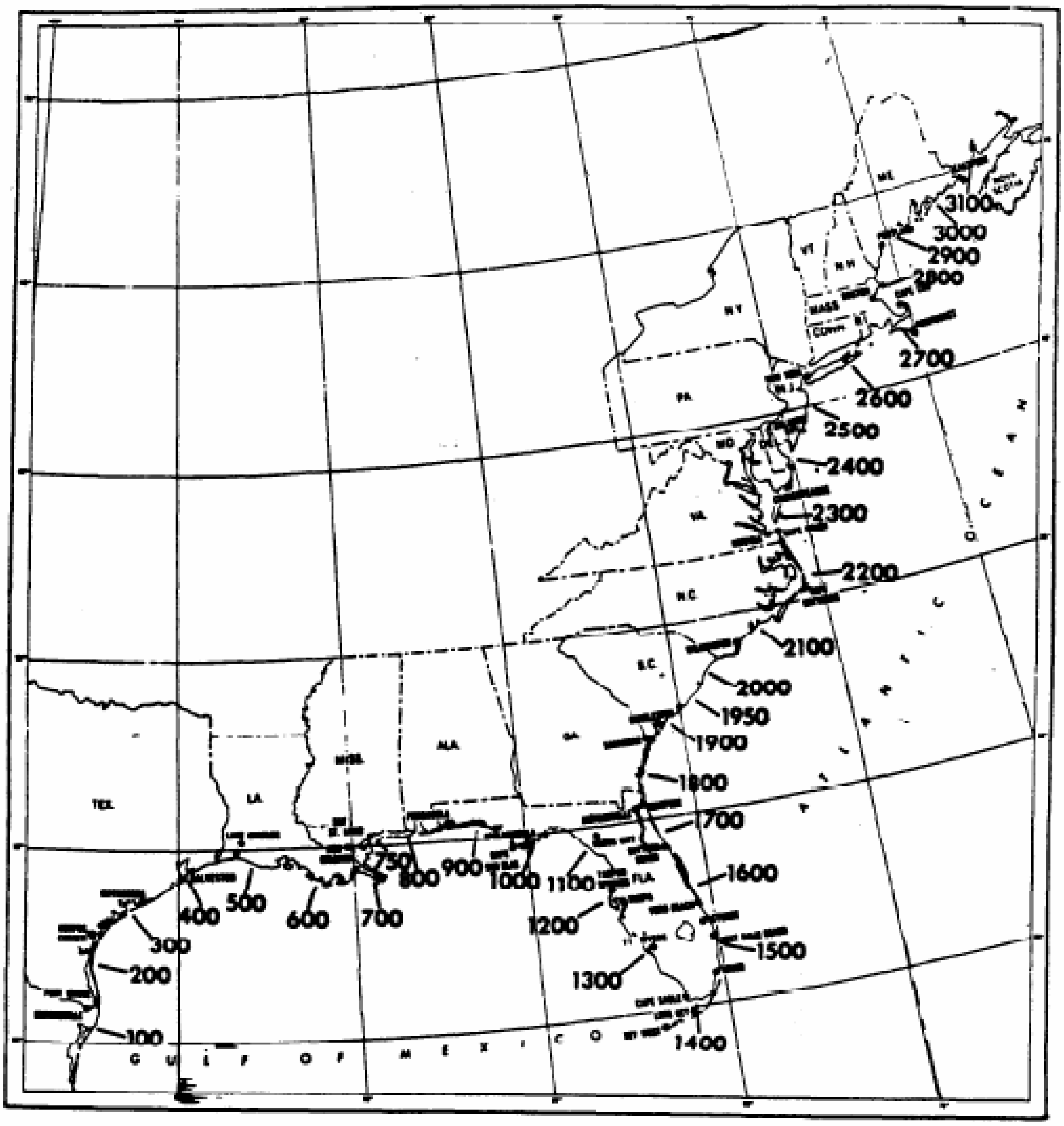

Table 1. Estimated Maximum Hurricane Wind Speed (MPH)

STA	RETURN PERIOD AT THE COAST 10	25	50	100	2000	AT 200 KM INLAND 10	25	50	100	2000
150	59	85	98	107	140	39	63	78	89	127
200	59	84	97	106	140	39	63	77	88	124
250	61	84	96	106	138	42	63	75	84	115
300	62	83	95	104	136	46	70	81	91	119
350	63	84	95	104	134	51	72	84	93	121
400	62	81	92	101	133	48	69	81	92	123
450	61	80	91	101	133	46	64	77	89	120
500	59	78	90	100	133	48	66	78	90	119
550	61	80	92	102	132	53	77	88	100	128
600	60	78	90	100	130	59	78	91	100	130
650	61	80	91	100	130	61	80	92	100	130
700	62	81	91	100	132	58	76	86	95	124
750	64	82	92	102	136	53	70	80	89	113
800	65	81	91	101	134	50	66	77	84	110
850	63	80	91	100	136	48	68	78	86	121
900	62	78	88	96	129	49	67	77	85	128
950	61	78	86	93	122	50	67	76	85	128
1000	59	76	84	90	117	47	61	69	76	107
1050	60	76	84	90	115	44	58	66	73	95
1100	61	77	87	93	125	40	56	65	74	102
1150	62	79	89	98	133	46	63	72	84	115
1200	66	84	95	103	138	51	70	81	92	128
1250	73	90	100	108	137	59	80	92	101	136
1300	78	95	104	111	137	66	84	96	104	136
1350	79	96	104	111	139	73	89	100	108	136
1400	80	97	106	113	140	76	92	103	111	139
1450	81	96	105	113	141	77	94	104	113	138
1500	79	93	103	111	139	73	92	101	110	138
1550	74	90	100	109	136	72	91	100	108	136
1600	70	89	99	107	132	64	83	95	105	132
1650	66	85	95	103	126	53	72	84	95	124
1700	62	82	90	98	117	44	61	72	82	116
1750	57	77	85	92	114	36	54	66	74	111
1800	56	76	85	92	117	35	50	62	74	110
1850	56	76	88	98	130	34	50	58	73	103
1900	60	81	93	104	140	40	59	70	82	114
1950	64	87	96	105	139	47	66	77	87	115
2000	64	85	96	106	136	55	75	85	94	121
2050	68	86	96	105	136	58	77	87	95	122
2100	70	84	98	106	136	63	83	93	101	134
2150	71	88	99	107	136	66	85	95	103	136
2200	70	87	97	105	134	69	87	98	105	134
2250	64	81	91	99	132	63	82	92	98	124
2300	58	75	86	95	128	57	74	85	93	121
2350	51	69	81	92	127	47	66	77	87	125
2400	48	65	78	91	125	40	61	77	87	125
2450	47	65	79	91	130	32	54	68	82	129
2500	49	72	87	98	136	31	52	69	83	120
2550	51	77	92	101	138	32	61	76	90	130
2600	53	81	95	104	140	37	70	84	96	133
2650	55	82	95	105	141	42	74	87	98	134
2700	54	80	93	104	139	41	76	89	99	132
2750	50	74	88	99	137	35	74	89	100	133
2800	46	69	82	96	133	26	66	81	92	127
2850	42	62	77	87	132	22	53	71	86	121
2900	39	59	71	85	128	21	46	66	83	117

Source: **Hurricane Wind Speeds in the United States**, National Bureau of Standards, 1980.

Table 2. Wind Hazard

Recurrence Interval (years)	Wind Speed (mph)		
	Coast	Project Site	125 mi. Inland
10	62	62	44
25	82	82	61
50	90	90	72
100	98	98	82
2000	117	117	116

The BC technical guidance hurricane hazards data for the U.S. territories were based on similar hazard data as referenced by the National Bureau of Standards, as shown in Table 3 below.

Table 3 Wind Speed Data (Sustained): Islands

Recurrence Interval (Years)	American Samoa (Pago Pago)	Federated States of Micronesia (Ponape)	Guam (Agana)
10	45	45	100
25	59	59	126
50	69	69	145
100	80	80	184
2000	138	138	190

Recurrence Interval (Years)	Hawaii (Honolulu)	Northern Mariana Islands (Saipan)	Palau (Koror)
10	49	100	70
25	71	127	91
50	87	147	107
100	100	155	125
2000	140	190	190

Recurrence Interval (Years)	Puerto Rico (San Juan)	Republic of Marshall Islands (Majuro)	Virgin Islands (St. Thomas)
10	80	34	80
25	95	39	95
50	104	53	104
100	113	61	113
2000	143	115	143

Sources:

Hawaii — Historic data on hurricanes. Roy T. Matsuda, National Oceanic and Atmospheric Administration, 1994.

Pacific Islands — Wind speed and recurrence interval data. Captain John Rupp, Joint Typhoon Warning Center, Guam Naval Facility, 1994.

American Samoa — Hurricane risk for this island is approximated as the same as Micronesia.

Virgin Islands — Hurricane risk for these islands is approximated as the same as South Florida.

Puerto Rico — Hurricane risk for this island is approximated as the same as South Florida.

The wind frequency data (i.e., 10-, 25-, 50-, 100-, and 2,000-years) at the site correspond to exceedance probabilities. The module does a regression analysis fit between the logarithm of exceedance probability and wind speed to obtain a smooth curve relating exceedance probability and wind speed. This regression fit gives the annual exceedance probability for all winds, in 1-mph increments of wind speed.

From the annual exceedance probabilities, calculated as described above, the Expected Annual Number of Wind Storms, as shown in the table below in a given Storm Class are calculated by the difference of the given wind speed and the wind speed at the top of the Storm Class range. For example, the expected annual number of Class 2 Storms (i.e., all winds between 96 and 111 mph) is calculated as the exceedance probability for a 96-mph wind minus the exceedance probability for a 111-mph wind. The hurricane wind speeds, which are used in the benefit-cost program, are all sustained wind speeds at 10 meters (about 33 feet) of elevation, in conformance with National Hurricane Center nomenclature.

Table 4. Default Estimates by Storm Class

Storm Class	Wind Speed (mph)	Default Estimate	User Estimate
0	60-73	3.321E-01	
1	74-95	1.372E-01	
2	96-110	2.731E-02	
3	111-130	1.469E-02	
4	131-155	1.101E-02	
5	>155	2.676E-03	

Recent Changes

The work and findings of Batts et al. (1980) have been updated with over $10 million of federally funded wind engineering research over the last 25 years. Wind speeds in coastal areas, associated return periods, and methods for predicting the annual number of wind storms are determined differently now than in 1980. The American Society of Civil Engineers (ASCE) produces consensus standards for the engineering field, one of which is titled, ASCE 7 - Minimum Design Loads on Buildings and Other Structures. ASCE 7 is the current standard for determining design loads that act on buildings. Specifically, Chapter 6 of ASCE 7 provides quantified site-specific wind speed design standards and wind-hazard data.

FEMA's MR2 version of the Hazards U.S. (HAZUS)-MH Hurricane Model uses the methodology from ASCE 7 to identify wind-hazard risks at a census tract level. The data stored in HAZUS represent 100,000 years of simulated hurricanes striking the United States, in addition to the historical storms of record. In HAZUS-MH, a user specifies the location of a building by entering the census tract, or alternately the latitude and longitude for a more precise location, and the software instantaneously returns site-specific wind-hazard data. For each building site, the user is also required to specify the surrounding terrain (per ASCE 7 methodologies) to override the default characteristics for the specified geographic area. These probabilistic and historical hazard data sets are available in the BCA methodology to identify the hazards at a particular site.

To provide the wind-hazard data in a format that is both user-friendly and compatible with the Hurricane-Wind BCA Module, the data from the MR2 version of the HAZUS-MH Hurricane Module have been simplified and the wind-speed data has been converted, as described below:

- In the MR2 version of the HAZUS-MH Hurricane Model, the user provides geographic coordinates or a census tract that would allow the software to apply the correct wind speeds for the site of interest. Conversely, the wind-hazard data in the most recent (July 2006) module for this guidance are presented by zip code, not latitude and longitude. More specifically, the wind speed reported here for each specified return period corresponds to the average of all census tracts that overlap the zip code. In other words, the wind speed can be considered a representative value for the zip code, which can also be considered a valid value for most buildings in the zip code.

Zip Code: 33129
City/State: Miami | Florida
County: Dade

Maximum Sustained Wind Speed* by Return Period
(*One-minute sustained wind speeds in open terrain)

10-year	25-year	50-year	100-year	2000-year
65	87	103	116	158

- The MR2 version of the HAZUS-MH Hurricane Model uses 3-second gusts to describe the wind hazard. To make these data compatible with the Hurricane-Wind BCA Module, the data were converted to 1-minute sustained wind speeds for entry into the module.

Since most current building codes and design standards **use a 3-second gust** as the basis of the design wind speed, **the revised wind speed data will be made available in 3-second gusts**. The figure below shows a sample exceedance map of the HAZUS-MH winds speeds (3-sec gust) for the 50-year and 100-year return periods compared to the ASCE 7 design standards.

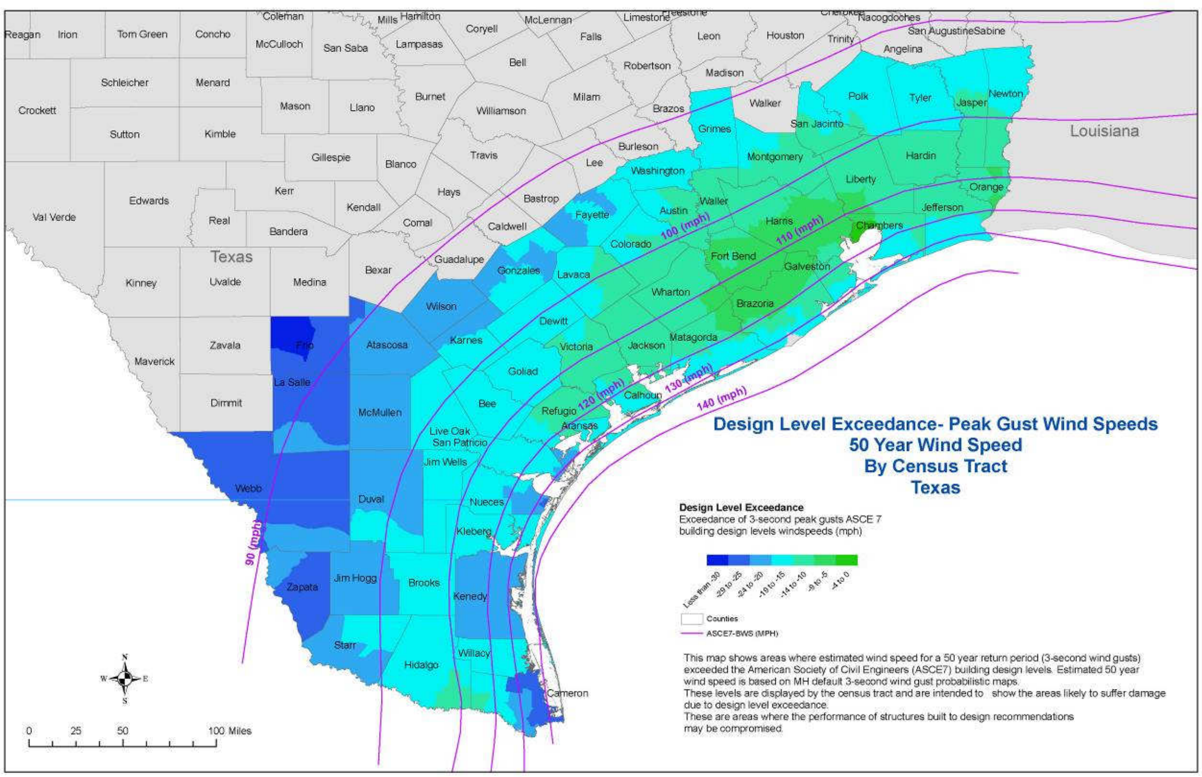

Figure 3 Design Level Exceedance Map—Peak Gust Wind Speeds 50-Year Return Period vs ASCE 7 Design Wind
Speeds

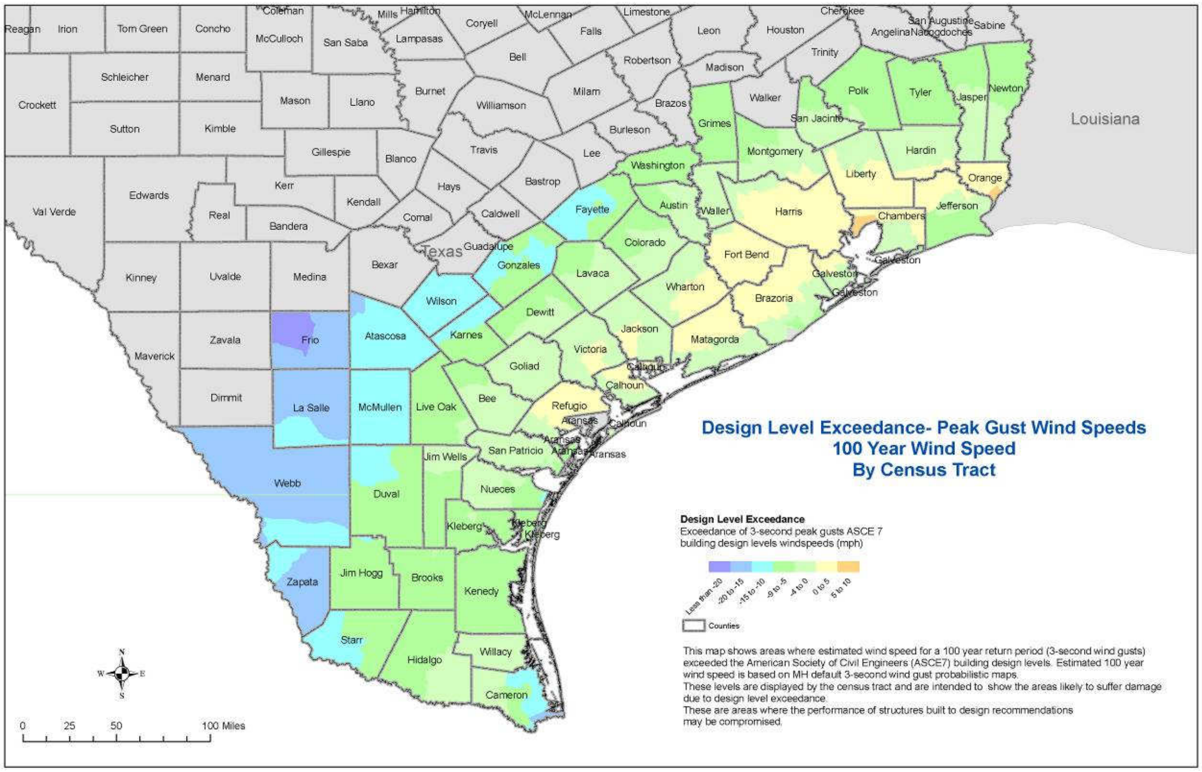

Figure 4 Design level Exceedance Map—Peak Gust Wind Speeds 100-Year Return Period vs ASCE 7 Design Wind Speeds

Proposed Changes

Based on the most recent methodology for using wind speeds generated by HAZUS-MH, it will be utilized to generate 3-second gust wind speeds for different return periods (10-, 20-, 50-, 100-, 200-, 500-, and 1000-year) for the areas along the U.S. Gulf and Atlantic Coasts, and Hawaii. The data will be available by zip code and latitude and longitude. However, HAZUS-MH currently does not include wind hazard data for the U.S. territories. Therefore, it's recommended to use hurricane wind speed design standards as provided in ASCE 7-05, which were developed using similar methodologies used in HAZUS-MH. Table 4, from Figure 6-1 of ASCE 7-05, provides the following wind speeds for the U.S. Territories:

Table 5. Wind Speeds for U.S. Territories

U.S. Territories	Wind Speeds (mph 3-second gust)
Puerto Rico	145

Guam	170
Virgin Islands	145
American Samoa	125

The actual return period, as represented by the design wind speed map in Table 5, varies from 50 to approximately 90 years. ASCE 7-05 contains adjustment factors to obtain the winds speeds for the 5-, 10-, 25-, 100-, 200-, and 500-year mean recurrence intervals (MRIs), as shown below:

ASCE 7-05 Table C6-7 Conversion Factors for Other Mean Recurrence Intervals (MRIs)

MRI (years)	V(50-yr) 85 - 100 mph	V(50-yr) > 100 mph
500	1.23	1.23
200	1.14	1.14
100	1.07	1.07
50	1.00	1.00
25	0.93	0.88
10	0.84	0.74 (76 mph min)
5	0.78	0.66 (70 mph min)

By using these adjustment factors, the following wind speeds for each of the return periods were calculated based on a V = 50-year return period:

For V = 50-year

Location	**5-YR**	**10-YR**	**25-YR**	**50-YR**	**100-YR**	**200-YR**	**500-YR**
Puerto Rico	96	107	128	145	155	165	178
Guam	112	126	150	170	182	194	209
Virgin Islands	96	107	128	145	155	165	178
America Samoa	83	93	110	125	134	143	154

As previously mentioned, HAZUS-generated wind speeds will be provided for the 10-, 20-, 50-, 100-, 200-, 500-, and 2,000-year return periods. These are slightly different, which will need to be addressed in calculating the Expected Annual Number of Wind Storms.

Expected Annual Number of Wind Storms

The Expected Annual Number of Wind Storms (EANWS) are calculated based on the wind recurrence data and the wind speed as shown in the table below.

EXPECTED ANNUAL NUMBER OF WIND STORMS

Storm Class	Wind Speed (mph)	Default Estimate	User Estimate
0	60-73	6.059E-02	
1	74-95	4.046E-02	
2	96-110	-9.779E-01	
3	111-130	9.980E-01	
4	131-155	1.606E-03	
5	>155	3.876E-04	

The EANWS are calculated as interval probabilities, which are the probabilities for each storm class by doing a regression analysis between the logarithm of the exceedance probability and wind speed, to obtain a smooth curve relating exceedance and wind speed. To determine the EANWS, the tables below are calculated in the BC module based on the recurrence interval, storm class, and wind speed.

Recurrence Interval	Exp. Prob.	ln(ExP)	Wind Speed	ln(WS)	slope
10	0.1	-2.303	64.000	4.159	--
25	0.04	-3.219	85.000	4.443	-3.229
50	0.02	-3.912	98.000	4.585	-4.870

100	0.01	-4.605	111.000	4.710	-5.565
2000	0.0005	-7.601	151.000	5.017	-9.734

Wind Speed (mph)	**Wind**	**ln (Wind)**	**if ln (WC)<25Y**	**if ln (WC)<50Y**	**if ln (WC)<100Y**	**if ln (WC)<2kY**	**Sum**	**ExP**	**Interval Probability**
60-73	60	4.094	-2.094	0.000	0.000	0.000	-2.094	0.12317	0.061
74-95	74	4.304	-2.771	0.000	0.000	0.000	-2.771	0.06258	0.040
96-110	96	4.564	0.000	-3.812	0.000	0.000	-3.812	0.02211	-0.978
111-130	111	4.710	0.000	0.000	0.000	0.000	0.000	1.00000	0.998
131-155	131	4.875	0.000	0.000	0.000	-6.218	-6.218	0.00199	0.002
>155	155	5.043	0.000	0.000	0.000	-7.855	-7.855	0.00039	0.000

Proposed Changes

The wind speed data will be provided in 3-second gusts to confirm the design standards, therefore the storm classes will not be used in the BC module. As a result, it will not be necessary to calculate interval probabilities. The EANWS will be calculated based on exceedance probabilities for the wind speeds at the 10-, 20-, 50-, 100-, 200-, 500-, and 1000-year return periods, which will be provided by HAZUS. Consideration will be given to the best regression analysis method to use to determine the exceedance probabilities and the number of points necessary to develop the curve. Frequency bands of 10-mph increments will be considered in the calculations.

Since HAZUS was developed to calculate damages and annual losses, information on how it calculates the EANWS will be evaluated.

Building Types

The current Hurricane-Wind BCA Module provides default damage function data (curves) for 5 building types that are outdated and no longer valid. The damages functions, as shown in Table 6, have the following limitations:

1. Only five types of building construction are included.
2. No distinction is made between different building heights. For example, a one-story non-engineered wood frame building and a two-story non-engineered wood frame building are grouped in the same class.

3. No distinction is made for differences in construction practices or the age of the structures.

4. Default damage estimates are for wind-damage; damages due to rain and water are considered indirectly as a consequence of expected wind damages to the building envelope.

5. Default damage estimates do not consider the variation in wind exposure, which may range from full exposure on an unprotected coastal site, to substantially reduced exposure at a site protected by topographic features.

6. Default damage estimates do not consider the variation in wind damage due to the amount and type of wind-blown debris, which may substantially increase wind damages.

Table 6
Default Building Wind Damage Data

Building Type / Storm Class	Non-Engineered, Wood	Non-Engineered, Masonry	Manufactured	Lightly Engineered	Fully Engineered	Other
0	0	0	10	0	0	0
1	7.5	5	25	5	2.5	0
2	20	15	50	15	5	0
3	50	40	80	40	20	0
4	90	80	100	80	40	0
5	100	100	100	100	60	0

Table 6 displays the default wind-damage estimates for Mitigation Effectiveness by storm class for the five building engineering types and the "other" classification included in the model.

Table 7
Default Mitigation Project Effectiveness

Building Type / Storm Class	Non-Engineered, Wood	Non-Engineered, Masonry	Manufactured	Lightly Engineered	Fully Engineered	Other

0	100	100	100	100	100	100
1	80	80	80	80	80	80
2	60	60	60	60	60	60
3	40	40	40	40	40	40
4	20	20	20	20	20	20
5	0	0	0	0	0	0

One major limitation of the Mitigation Effectiveness Damage Functions is that the values do not account for different types of improvements to the building. For example, the percentages are the same, independent of whether the roof or walls are retrofitted, or whether shutters are installed, or even if all three are performed.

Recent Changes

To facilitate the entry of more accurate data into the module, Wind Damage Functions for 51 building types (including manufactured housing) have been provided in the Version 3.0 (July 2006) of the Hurricane BC module. These data have also been extracted from the HAZUS-MH Hurricane Model. The table below, titled "Table 1 – Building Types for Use in the Hurricane-Wind Full Data Module "presents the 51 building types provided in this guidance. The detailed building data and damage functions are provided in the Wind Hazard Damage Function software. Specific design and construction information about the building types used may be found in the HAZUS-MH Hurricane Model Technical Manual, Section 6. Appendix A provides a description of the 51 building types.

Table 1: Building Types for Use in the Hurricane-Wind Full Data Module

Building Category	Bldg No.	Descriptive Name	HAZUS Name	Roof Shape	Roof Cover
Wood Frame, Single Family	1	Non-eng-Wood-Hip-Shingle[1]	WSF1	Hip	Shingle
Wood Frame, Single Family	2	Non-eng-Wood-Gable-Shingle[2]	WSF1	Gable	Shingle
Un-reinforced Masonry, Single Family	3	URM[3]-Hip-Shingle	MSF1	Hip	Shingle
Un-reinforced Masonry, Single Family	4	URM-Gable-Shingle	MSF1	Gable	Shingle
Manufactured Housing	5	Pre-1976 Manufactured Units	MHPHUD	Gable	Shingle
	6	1976-1994 Manufactured Units	MH76HUD	Gable	Shingle
Zone 1 installation	7	Post-1994 Manufactured Units	MH94HUDI	Gable	Shingle
Zone 2 installation	8	Post-1994 Manufactured Units	MH94HUDII	Gable	Shingle
Zone 3 installation	9	Post-1994 Manufactured Units	MH94HUDIII	Gable	Shingle
Wood Frame Non-Engineered	10	Non-eng-Wood-Gable-Shingle	WMUH1	Gable	Shingle
	11	Non-eng-Wood-Hip-Shingle	WMUH1	Hip	Shingle
	12	Non-eng-Wood-Flat-BUR[4]	WMUH1	Flat	BUR
	13	Non-eng-Wood-Flat-SPM[5]	WMUH1	Flat	SPM
Wood Frame, Engineered (load path)	14	Eng-Wood-Gable-Shingle	WMUH1	Gable	Shingle
	15	Eng-Wood-Hip-Shingle	WMUH1	Hip	Shingle
	16	Eng-Wood-Flat-BUR	WMUH1	Flat	BUR
	17	Eng-Wood-Flat-SPM	WMUH1	Flat	SPM
Masonry Non-Engineered	18	URM-Gable-Shingle	MMUH1	Gable	Shingle
(Un-reinforced)	19	URM-Hip-Shingle	MMUH1	Hip	Shingle
	20	URM-Flat-BUR	MMUH1	Flat	BUR
	21	URM-Flat-SPM	MMUH1	Flat	SPM
Masonry Non-Engineered	22	RM[6]-Gable-Shingle	MERBL	Gable	Shingle
(Reinforced)	23	RM-Hip-Shingle	MERBL	Hip	Shingle
	24	RM-Flat-BUR	MERBL	Flat	BUR
	25	RM-Flat-SPM	MERBL	Flat	SPM
Fire Station - Wood Frame	26	Non eng-Wood Fire Station	WSF2	Gable	Shingle
Fire Station - URM	27	URM Fire Station	MSF2	Gable	Shingle
Fire Station - RM	28	RM Fire Station	MSF2	Gable	Shingle
Masonry Strip Mall	29	URM-BUR-Light Commercial	MLRM1	Flat	BUR
(Un-reinforced)	30	URM-SPM-Light Commercial	MLRM1	Flat	SPM
Masonry Strip Mall	31	RM-BUR-Light Commercial	MECBL	Flat	BUR
(Reinforced)	32	RM-SPM-Light Commercial	MECBL	Flat	SPM
Masonry Industrial - URM	33	URM-SPM-Industrial	MLRI	Flat	SPM
Masonry Industrial - RM	34	RM-SPM-Industrial	MLRI	Flat	SPM
Masonry Engineered Commercial	35	RM-Eng-BUR-Commercial	MECBM	Flat	BUR
	36	RM-Eng-SPM-Commercial	MECBM	Flat	SPM
Steel Frame Engineered Commercial	37	STL-Eng-BUR 1-2 Stories	SECBL	Flat	BUR
	38	STL-Eng-SPM 1-2 Stories	SECBL	Flat	SPM

1 Hip Roof = A roof that slopes up from all four sides of a building.
2 Gable Roof = A ridged roof that slopes up from only two sides of a building.
3 URM = Unreinforced Masonry
4 BUR = Built-Up Roof
5 SPM = Single-Ply Membrane
6 RM = Reinforced Masonry

Building Category	Bldg No.	Descriptive Name	HAZUS Name	Roof Shape	Roof Cover
	39	STL-Eng-BUR 3-5 Stories	SECBM	Flat	BUR
	40	STL-Eng-SPM 3-5 Stories	SECBM	Flat	SPM
	41	STL-Eng-BUR 6+ Stories	SECBH	Flat	BUR
	42	STL-Eng-SPM 6+ Stories	SECBH	Flat	SPM
Concrete Engineered Commercial	43	RC-Eng-BUR 1-2 Stories	CECBL	Flat	BUR
	44	RC-Eng-SPM 1-2 Stories	CECBL	Flat	SPM
	45	RC-Eng-BUR 3-5 Stories	CECBM	Flat	BUR
	46	RC-Eng-SPM 3-5 Stories	CECBM	Flat	SPM
	47	RC-Eng-BUR 6+ Stories	CECBH	Flat	BUR
	48	RC-Eng-SPM 6+ Stories	CECBH	Flat	SPM
Pre-Engineered Metal	49	PEMB-Small	SPMBS	Flat	Metal
	50	PEMB-Medium	SPMBM	Flat	Metal
	51	PEMB-Large	SPMBL	Flat	Metal

The list of building types provided in this guidance greatly increases the number available for analysts to use in the current Hurricane-Wind BCA Module. Analysts who use HAZUS-MH may be aware that the loss-estimation software has hundreds of options for building types based on construction materials, age of structure, condition of structure, presence of load path from the roof to the foundation, roof covering type, roof decking type, roof structure type, connection and fastening schedules, percentage of windows and doors, and many other factors. To develop a representative list of building types for use in this software, FEMA made general assumptions about the different building types and the other factors described above.

The following assumptions, conditions, and terms apply to all of the building types presented in this guidance:

- The building is generally in good condition, with no major maintenance issues that would prevent the building structure or exterior from performing as designed. The building is well constructed.
- The building's openings (windows and doors) are not protected from wind and windborne debris.
- There are three roof covering choices available:
  - Shingle is a roof with an asphalt shingle, tile, or metal panel roof system.
  - BUR is a built-up roof system that may be hot-mopped or fully adhered.
  - SPM is a single-ply membrane roof system.
- The terrain is "Light Suburban."

- The Wind Damage Functions (WDFs) values (percentages) were obtained from HAZUS for each Storm Class (Category 0 to 5) at the following 1-minute sustained wind speeds:
  - Category 0 → 60 mph
  - Category 1 → 74 mph
  - Category 2 → 96 mph
  - Category 3 → 111 mph
  - Category 4 → 131 mph
  - Category 5 → 155 mph

More details and assumptions of the various buildings and components are discussed in greater detail in Appendix 1.

Proposed Changes

Based on the current approach of re-engineering the BC model, consideration should be given to whether the current methodology described above, which uses 51 building types as provided in the current Version 3.0 Hurricane BC Module Patch, is still sufficient. As previously mentioned, these building types were identified to be a representative list of buildings, and to have a simplified approach, compared to the hundreds of building scenarios in HAZUS.

The following items will be considered:

- Terrain
- Differences in building practices by region or State
- Variations in Building Codes. This will also need to be addressed due to "code plus" mitigation, as described below
- Options to select a WDFs for a different building or roof system for "Before-Mitigation" vs "After-Mitigation." For instance, if the before-mitigation system is un-reinforced masonry and the after-mitigation is reinforced, or if the roof cover changes from BUR to SPM
- Complete set of damage curves for all the building types

In the current version of the BC module patch, the damage functions are based on specific points along the curve for each building type. The points were selected based on the median wind speed for each storm class. Since the storm class will no longer be a part of the new BC module, and the WDFs will vary by wind storm for each of the seven return periods from 10- to 1000-year, the complete damage curve will be necessary for each building type and configuration.

It will be necessary to have several working group meetings, consisting of the HAZUS Hurricane Wind developers and the BC team, to address the issues outlined above.

Code Plus

There currently is no formal procedure or specific data in the BC module that addresses mitigating a building by constructing it above code. FEMA Region IV has developed an Experimental BC Hurricane module that is being used to evaluate some code plus projects in Mississippi and Florida.

In order to address code plus buildings, it would be necessary to have damage functions for current code-compliant buildings (both ICC-complaint buildings and building built to a variety of codes prior to the ICC—some of which may have been hazard-resistant codes, while others may not have been) and damage functions for building design above the current code (code plus). Code plus typically refers to buildings that have been: (1) designed and constructed to a higher wind speed than what's required in the code; (2) the building's openings were protected with shutters, screens, or impact-resistant glass, if not currently required; or (3) both items. The current BC wind module provides a number of building types that are engineered and would be considered to be code compliant at the time the building was constructed. However, to evaluate a code plus project, the building should be evaluated based on the code that is currently adopted by the jurisdiction. In many areas, the codes have changed and States and communities have adopted one of the following codes: the International Building Code (IBC), the International Residential Code (IRC), Florida Building Code (FBC), and the Texas Insurance Code (TIC), the last of which is promulgated and enforced by Texas Department of Insurance for the coastal counties along the Gulf Coast of Texas. However, many communities or counties are still using and enforcing the Standard Building Code (SBC, 1994 or 1997 editions) or have not adopted any code.

The damage functions available in the BC model (Version 3.0 – patch) generated from HAZUS are based on the buildings constructed under the older codes, which generally used somewhat different design wind speeds. The SBC (1979) adopted by many communities had basic design wind speeds that ranged from 90–110 fastest mile, if converted to 3-second gusts, which is used by current model codes, would be equivalent basic wind speeds for design that range from 110 -130 mph. The current model code and newer state codes (IBC/IRC, FBC, and TIC) take the basic (design) wind speeds directly from ASCE 7, which typically show basic wind speeds ranging from 90-130 mph (3-second gust) to be used for design, although some jurisdictions will require basic wind speeds as high as 140-150 mph. Prior to the development of the wind speed maps and design procedures provided in ASCE 7, the American National

Standard Institute (ANSI) A58.1-1982 was considered the reference design standard for wind design and construction. Starting in 1985, the SBC modified the design wind speeds required by the code to match those required by the ANSI standard. These design wind speeds were reduced from 90-110 (fastest mile) in the 1979 SBC to generally 90-95 mph (fastest mile), which correlates to 110-115 mph (3-sec gust).

Therefore, depending on the building code used at the time, these wind speeds may need to be adjusted from fastest-mile to 3-second gust wind speeds when predicting the performance of buildings in high-wind regions.1 For buildings constructed to the SBC, the South Florida Building Code (SFBC), or any code from 1999 or older, use the table below to adjust the wind speed.

The table below is taken from the 2004 Florida Building Code (FBC), Section 1609.3.1 Wind Speed Conversion.

TABLE 1609.3.1
EQUIVALENT BASIC WIND SPEEDS a, b, c

V 3S	85	90	100	105	110	120	125	130	140	145	150	160	170
V fm	70	75	80	85	90	100	105	110	120	125	130	140	150

For SI: 1 mile per hour = 0.44 m/s.
a. Linear interpolation is permitted.
b. V 3S is the 3-second gust wind speed (mph).
c. V fm is the fastest mile wind speed (mph).

Besides the basic wind speed used in the design of the building, there are several other factors to be considered, including external pressure coefficients (for calculating wind loads on building surfaces, which affect the design pressures for window and door openings and the corners of the roof and walls). Another key factor is design for internal pressures. Most of the older building codes did not account for internal pressures, which are taken into account in the damage functions in HAZUS. Some of the design requirements of the new model codes include increases in the design pressures at window and door openings, corners of the roof and wall, and account for internal pressure, either partially or fully, depending on the importance of the building. The protection of openings from damage or breach from wind pressures and windborne

[1] NOTE: Basic (Design) Wind Speeds in different building codes and standards are often compared to understand and predict building performance. Comparing the basic (design) wind speed is only on part of this comparison. When attempting to compare the design and strength of a building designed to an older code to that of a newer code to predict wind resistant and performance, it is assumed and acknowledged that each code and standard have different design requirements, coefficients that relate to the wind speed measure, and possibly pressure coefficients. All these factors must be properly considered and included in the comparison. The reader should not take a basic (design) wind speed from one code or standard and input it into the design formulas of another code or standard, as the wind pressures calculated may not be correct if appropriate conversions were not performed.

debris in certain regions is also an important design requirement of the new code and should also be considered; the presence of openings (or lack thereof) may also affect the appropriate selection of the design parameters to account for internal pressures in buildings.

HAZUS Damage Functions

The building types identified from HAZUS that are currently being used in the BC Hurricane-Wind Module (Version 3.0 – patch) that might be considered in the code plus analysis are the Steel and Concrete Engineered buildings, which are described below.

Wood Frame, Engineered with Continuous Load Path (Building Numbers 14-17) (WMUH1). These buildings are newer wood frame structures typical of a one- or two-story multi-family dwelling or hotel/motel. They were designed or constructed to wind design requirements or prescriptive guidelines of the Southern Building Code Congress International's 1994/1997 Standard Building Code or 1999 SSTD 10-99 Standard for Hurricane Resistant Residential Construction, or the 1995 (or later) ASCE 7. They may also be wood structures that have been designed by an engineer or architect to resist wind loads. Buildings with and without attached garages may be included. Users will need to specify which roof geometry (gable, hip, or flat) and which roof covering (shingle, BUR, or SPM) best represent their structure.

Commercial (Building Numbers 35-48) (MECBM/SECBL/SECBM/SECBH/CECBL/ CECBM/ CECBH). These buildings are typical of multi-story concrete or steel frame buildings or fully reinforced masonry and reinforced concrete structures. Two- to four-story office buildings and hospitals are typical examples of these building types. They were designed or constructed to wind design requirements of the ANSI A58.1 or ASCE 7-88 (or later versions). These structures may or may not have been designed for use as critical or essential facilities, but they were designed by an engineer or architect to resist wind loads. Users will need to specify which structure type (masonry, concrete, or steel) and which roof covering (BUR or SPM) is the best representation of their structure.

Commercial (Building Numbers 35-48, MECBM/SECBL/SECBM/SECBH/CECBL/CECBM/CECBH). These buildings are typical of multi-story concrete or steel frame buildings or fully reinforced masonry and reinforced concrete structures. Two- to four-story office buildings and hospitals are typical examples of these building types. They were designed or constructed to the wind design requirements of ANSI A58.1 or ASCE 7-88 (or later versions). These structures may or may not have been designed for use as critical or essential facilities, but they were designed by an engineer or architect to resist wind loads. Users will need to specify which structure type (masonry, concrete, or steel) and which roof covering (BUR or SPM) is the best representation of their structure.

As stated in the HAZUS – MH MR3 Technical Manual, Section 6.12, the damage functions for the fully engineered buildings being considered have a structural system comprised of either concrete or steel. In the case of the concrete buildings, it has been assumed that the roof slab is a poured concrete slab that cannot be penetrated by water if the roof cover fails. Thus, in the case of concrete buildings, the damage state of the building is driven entirely by the performance of the windows. The steel buildings are modeled as having an open web steel joist roof system, with a metal deck welded to the joists. The uplift capacities of the metal roof panels are estimated based on the ASCE design code for a 100-mph fastest mile design speed.

The mitigation options for the two types of buildings are as follows:

1) Concrete: mitigation options are shutters only
2) Steel: mitigation options are either roof upgrades, or shutters, or both

The damage functions for the engineered buildings are fairly constant for before and after mitigation for roof upgrades with 70 percent damage at a category 3 (111 mph sustained). However, they drop to less than 20 percent for after-mitigation for protection of windborne debris using shutters or impact-resistant glass.

Summary

The main issues that need to be considered in evaluating "code plus" buildings are wind speed, and the variation in the design requirements, including external pressure coefficients and internal pressures, for the different building codes. As previously mentioned, the reader should not take a basic [design] wind speed from one code or standard and use it in the design formulas of another code or standard, as the wind pressures calculated may not be correct if appropriate conversions were not performed.

Since the current damage functions in the Hurricane BC model are based on the older codes, which generally don't take account for internal pressure; don't have lower design pressures at various areas of the roof and the window and door openings; and don't require windborne debris impacts, it is recommended to develop new damage curves for buildings constructed to these model codes (IBC/IRC, FBC, and TIC). Damage curves would need to be developed for buildings constructed to these buildings and curves for higher standards (i.e., higher wind speeds), thus making it "Code Plus."

Since some jurisdictions don't have a code or still use the 1994 or 1997 SBC, or earlier editions, curves from the BC model patch (version 3.0) could be initially identified for before-mitigation conditions and modified to account for code plus (after-mitigation) conditions.

Some issues to consider:

- For code plus, would this automatically assume shutters or debris impact glass would be installed?

- Would FEMA want to provide mitigation funds to communities who currently have not been proactive by adopting a model building code, which is the first step in mitigation? The benefits would be much higher for those communities that have not adopted a building code, or are using an older code. This would then penalize the States and communities that have kept current with the model codes.

In order to develop the damage functions for current codes, it will be necessary to meet with the HAZUS developers to discuss the issues and develop the new damage curves.

References

Batts, M. et al. 1980. *Hurricane Wind Speeds in the United States*. Building Science Series 124, National Bureau of Standards, Washington, DC.

Andrews, R.N.L. 1982. Benefit-Cost Analysis as Regulatory Reform, in *Cost-Benefit Analysis and Environmental Regulations: Politics, Ethics and Methods*, D. Swartzman, R.A. Liroff, and K.G. Croke (editors), The Conservation Foundation, Washington, DC.

Hurter, A.P. Jr., G.S. Tolley, and R.G. Fabian. 1982. Benefit-Cost Analysis and the Common Sense of Environmental Policy, in *Cost-Benefit Analysis and Environmental Regulations: Politics, Ethics and Methods*, D. Swartzman, R.A. Liroff, and K.G. Croke (editors), The Conservation Foundation, Washington, DC.

Leman, C.K. 1989. The Forgotten Fundamental: Successes and Excesses of Direct Government, in *Beyond Privatization: The Tools of Government Action*, L.M. Salamon (editor), The Urban Institute Press, Washington, DC.

Ward, W.A., and B.J. Deren. 1991. *The Economics of Project Analysis, A Practitioner's Guide*. Economic Development Institute of the World Bank.

Appendix A

The following are the assumption for developing the 51 building Types:

Detailed descriptions of the 12 general Building Categories listed in Table 1 are provided below. The user will select a building type to enter into the Hurricane-Wind BCA Module based on these general Building Categories. A total of 51 possible building types can be selected from the 12 general Building Categories, with differentiation according to construction, number of stories, roof shape, and roof coverings. Additional details and descriptions may be found in Section 6 of the HAZUS-MH Hurricane Model Technical Manual.

<u>Wood Frame Single Family (Building Numbers 1-2), (WSF1).</u> These buildings are typical of old wood frame single-family homes. They are one- or two-story dwellings that are marginally engineered or non-engineered. They were likely designed or constructed prior to wind design requirements or prescriptive guidelines, or they are wood structures that have not been designed by an engineer or architect. All of these buildings have been modeled as asphalt shingle roofs with an attached garage. Users will need to specify which roof geometry (gable or hip) is the best representation of their structure.

<u>Un-reinforced Masonry Single Family (Building Numbers 3-4), (MSF1).</u> These buildings are typical of un-reinforced masonry single-family homes. They are one- or two-story dwellings that are marginally engineered or non-engineered. They were likely designed or constructed prior to wind design requirements or prescriptive guidelines, or they are un-reinforced masonry structures that have not been designed by an engineer or architect. All of these buildings have been modeled as asphalt shingle roofs with an attached garage. Users will need to specify which roof geometry (gable or hip) is the best representation of their structure.

<u>Manufactured Housing (Building Numbers 5-9) (MHPHUD/MH76HUD/MH94HUDI/II/III).</u> These manufactured housing unit designations represent three types of manufactured housing based on the regulatory requirements governing their design. The user should select if the unit has been designed and fabricated to one of three designations. The first are pre-1976 manufactured units designed and fabricated prior to significant regulation of the industry. The second are the 1976-1994 manufactured units designed and fabricated to the U.S. Department of Housing and Urban Development (HUD) regulations known as the "Manufactured Home Construction and Safety Standards (MHCSS)," 24 CFR Part 3280, sometimes referred to as "HUD-code homes." The third are the post-1994 units, designed and fabricated to the wind loading requirements increased in response to years of excessive storm-induced damage as part of HUD Final

Rule 59 FR 2456, which revised several provisions in 24 CFR 3280.305(c) to improve the resistance of manufactured homes in high wind zones to wind damage. The post-1994 selection assumes the proper Zone I, II, or III units have been installed in the correct wind zone. All homes are assumed to be non-anchored units.

Wood Frame Non-Engineered (Building Numbers 10-13), (WMUH1). These buildings are typical of older wood frame structures. They are one- or two-story multi-family dwellings or hotels/motels that are marginally engineered or non-engineered. They were likely designed or constructed prior to wind design requirements or prescriptive guidelines, or they are wood structures that have not been designed by an engineer or architect. Buildings with and without attached garages may be included. Users will need to specify which roof geometry (gable, hip, or flat) and which roof covering (shingle, BUR, or SPM) is the best representation of their structure.

Wood Frame, Engineered with Continuous Load Path (Building Numbers 14-17), (WMUH1). These buildings are newer wood frame structures typical of a one- or two-story multi-family dwelling or hotel/motel. They were designed or constructed to wind design requirements or prescriptive guidelines of the Southern Building Code Congress International's 1994/1997 Standard Building Code or 1999 SSTD 10-99 Standard for Hurricane Resistant Residential Construction, or the 1995 (or later) ASCE 7. They may also be wood structures that have been designed by an engineer or architect to resist wind loads. Buildings with and without attached garages may be included. Users will need to specify which roof geometry (gable, hip, or flat) and which roof covering (shingle, BUR, or SPM) best represent their structure.

Masonry Non-Engineered (Building Numbers 18-21), (MMUH1). These buildings are typical of older un-reinforced masonry (URM) structures. They include typical standalone buildings used for light commercial/industrial use, and one- or two-story multifamily URM dwellings or hotels/motels that are non-engineered. They were designed or constructed prior to wind design requirements or prescriptive guidelines, or they are wood structures that have not been designed by an engineer or architect. Buildings with and without attached garages may be included. Users will need to specify which roof geometry (gable, hip, or flat) and which roof covering (shingle, BUR, or SPM) is the best representation of their structure.

Masonry Non-Engineered (Building Numbers 22-25), (MERBL). These buildings are typical of older partially reinforced masonry (PRM) and fully reinforced masonry (RM) structures. They include typical stand-alone buildings used for light commercial/industrial use, one-story multi-family URM dwellings, and hotels/motels that are marginally engineered or non-engineered. They were designed or constructed prior to wind design requirements or prescriptive guidelines, or they are wood structures that have not been designed by an engineer or architect. Buildings with and without attached garages may be included. Users will need to specify which roof geometry (gable, hip, or flat) and which roof covering (shingle, BUR, or SPM) is the best representation of their structure.

Fire Stations (Building Numbers 26-28), (WSF2/MSF2). These buildings are representative of one- and two-story fire stations that have both apparatus bay areas with large overhead doors and office/barracks/support areas. These buildings are typical of older structures that were marginally engineered or non-engineered. Although they may have been designed by an engineer or architect, they were likely designed or constructed prior to wind design requirements or prescriptive guidelines. The user will need to specify if the walls of the building are constructed of wood framing, URM, or RM systems. No options for different roof shape or coverings are provided.

Masonry Strip Mall (Building Numbers 29-32), (MLRM1/MECBL). These buildings are typical of URM and RM structures. They are typically one-story structures such as strip malls and small commercial centers, and may include stand-alone buildings used for light commercial/industrial use and hotels/motels that are marginally engineered or fully engineered. Although they may have been deigned by an engineer or architect, they were likely designed or constructed prior to wind design requirements or prescriptive guidelines. Users will need to specify which roof covering (BUR or SPM) is the best representation of their structure. The roof decks are metal deck systems lightly connected/fastened to open-web steel joists or other light framing system with minimal connections to the top of the wall.

Masonry Industrial (Building Numbers 33-34), (MLRI). These buildings are typical of URM and RM structures. They are typically much larger than the Masonry Strip Mall Building Types (Nos. 29-32), and they are more typical of buildings the size of a large department store. Although they may have been deigned by an engineer or architect, they were likely designed or constructed prior to wind design requirements or prescriptive guidelines. Users will need to specify which roof covering (BUR or SPM) is the best representation of their structure. The roof decks are metal deck systems lightly connected/fastened to open-web steel joists or other light framing system with minimal connections to the top of the wall.

Commercial (Building Numbers 35-48), (MECBM/SECBL/SECBM/SECBH/CECBL/ CECBM/ CECBH). These buildings are typical of multi-story concrete or steel frame buildings or fully reinforced masonry and reinforced concrete structures. Two- to four-story office buildings and hospitals are typical examples of these building types. They were designed or constructed to wind design requirements of the ANSI A58.1 or ASCE 7-88 (or later versions). These structures may or may not have been designed for use as critical or essential facilities, but they were designed by an engineer or architect to resist wind loads. Users will need to specify which structure type (masonry, concrete, or steel) and which roof covering (BUR or SPM) is the best representation of their structure.

Pre-Engineered Metal (Building Numbers 49-51), (SPMBS/SPMBM/SPMBL). These buildings are pre-engineered metal buildings less than 50,000 square feet in area. They are typical of industrial and commercial use buildings that were designed and constructed by manufacturers of pre-engineered systems such as Butler, Nucor, and many others. They typically have open floor plans and multiple, large overhead doors providing access to the interior. These buildings most commonly are clad with metal panels on both the roof and wall surfaces; however, it is common to see masonry wall cladding on some or all of the exterior walls.

Mitigation Options for Buildings

In addition to the before-mitigation building damage data provided, after-mitigation damage data is also provided for each of the building types. Available mitigation options depend upon the building type selected. As previously stated, the source for these data is the HAZUS-MH loss estimation methodology. Since HAZUS-MH is an evolving tool, there are limitations to the data available, and not all possible mitigation upgrades were available for modeling. Where mitigation options are not provided for a particular building type, users should select the mitigation option, or combination of mitigation options, most similar to the mitigation project described in their application. Descriptions of the different mitigation options are provided below.

Install Roof-Wall Load Path Upgrade. This mitigation option is to improve and upgrade the structural system of a building to transfer loads from the roof to the foundation. In wood frame construction, this retrofit would provide positive connection from the roof framing to the walls, better connections within the wall framing, and connections from the wall framing to the foundation system. In a masonry building with some vertical reinforcing present, this retrofit would provide positive connection from the roof framing to the walls, better connections within the wall framing, and connections from the wall framing to the foundation system. This option is not applicable to all building types.

Install Roof Deck-Roof Covering Upgrade (see "Upgraded Roof"). This mitigation option is to improve and upgrade the roof deck and roof coverings of a building. In wood-framed roofs this upgrade includes better connection of the roof decking to the rafters or trusses, typically through the use of larger nails at closer spacing than originally provided; replacement of degraded deck panels is appropriate. For metal deck roof systems, this upgrade may include replacement of panels and the use of additional fasteners to connect the deck to supporting members or it may just consist of the installation of additional fasteners through the existing deck. In all cases, the increased fastener schedules should be based on prescriptive guidance appropriate for the design wind speed at the project site. It is assumed that a secondary layer of protection will be installed atop the roof deck prior to the installation of the new roof coverings. For all buildings with shingle roof types, it is assumed that new roof coverings are rated to resist winds and wind pressures of 110 mph.

Install Shutter or Window Protection System (see "Shutters"). This mitigation option is to protect all windows and doors with shutters, laminations, or other systems that meet the debris impact and wind pressure design requirements of the IRC/IBC. Selection of this mitigation option assumes that all openings of a building will be protected, including garage doors on residential buildings, large overhead doors on commercial buildings, and the apparatus bay doors at fire stations.

Install Combined Roof-Wall Load Path and Roof Deck-Roof Covering Upgrade. This mitigation option is a combination of the Roof-Wall Load Path Upgrade and the Roof Deck-Roof Covering Upgrade described above.

Install Combined Roof-Wall Load Path and Shutter or Window Upgrade. This mitigation option is a combination of the Roof-Wall Load Path Upgrade and the Shutter or Window Upgrade described above.

Install Roof Deck-Roof Covering and Shutter or Window Protection Upgrade. This mitigation option is a combination of the Roof Deck-Roof Covering Upgrade and the Shutter or Window Upgrade described above.

Install All Available Upgrades (Roof-Wall Load Path, Roof Deck-Roof Covering, and Shutter or Window Protection). This mitigation option is the most comprehensive for a particular building type. The mitigation will include all mitigation options (when available).