Building Codes Save: A Nationwide Study

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

Appendices / November 2020

FEMA

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APPENDIX A:

CoreLogic Data Summary and AALA Results

A.1 CoreLogic Data Summary

Table A1-1: CoreLogic Dataset Primary Filtering by State

State / District of Columbia	FIPS	State Population (Based on 2010 Census)	CoreLogic Raw Parcel Count	Level 1 Parcels Remove Parcels with Hazus Occupancies not evaluated (Vacant, Unknown, Blank)	Level 2 Parcels with Year Built > 1999 or Year Built = 0 and Effective Year Built > 1999	Level 3A Parcels with Square Footage ≥ 0	Level 3B Parcels Merge Stacked Parcels to Single Parcel Based on Land Use	Level 4 Parcels Parcels with Square Footage ≥ 500	Level 5 Parcels Merge COM and IND Parcels on Large Footprints	Level 6 Building Centroids Convert dataset from Parcels to Building Centroids and Merge Non-Symmetrical Stacked Parcels	Level 7 Building Centroids Filter out Counties with Less than 10 Building Centroids
Alabama	01	4,779,736	3,132,055	2,416,069	374,504	338,692	337,128	335,068	331,069	374,443	374,443
Alaska	02	723,708	372,187	246,357	44,443	44,073	44,073	40,568	40,402	41,493	41,492
Arizona	04	6,392,017	3,258,781	2,555,650	762,993	751,773	741,501	737,909	698,943	751,206	751,206
Arkansas	05	2,915,918	1,853,351	1,145,504	198,509	195,064	194,859	193,670	193,281	222,671	222,661
California	06	37,253,956	12,158,000	10,698,420	1,439,650	1,432,938	1,283,171	1,281,933	1,244,660	1,388,979	1,388,971
Colorado	08	5,029,196	2,608,159	2,200,641	484,307	480,280	448,803	445,159	407,488	458,424	458,424
Connecticut	09	3,574,097	1,207,593	1,070,432	80,449	80,071	78,453	78,366	76,203	85,483	85,483
Delaware	10	601,723	421,745	357,324	77,625	77,150	77,150	76,788	72,740	77,264	77,264
District of Columbia	11	897,934	136,971	123,213	6,832	6,429	6,414	6,404	4,660	4,762	4,762
Florida	12	18,801,310	9,646,482	7,901,491	1,873,273	1,861,258	1,761,289	1,754,062	1,633,334	1,775,701	1,775,701
Georgia	13	9,687,653	4,545,115	4,172,012	932,224	929,862	901,781	899,523	851,889	923,382	923,382
Hawaii	15	1,360,301	380,333	280,823	47,129	46,995	46,995	46,141	46,105	54,402	54,402
Idaho	16	1,567,582	1,044,701	833,618	171,592	167,932	165,665	164,387	161,401	183,210	183,208
Illinois	17	12,830,632	5,316,859	4,526,211	298,420	284,163	258,704	258,301	241,873	261,805	261,798
Indiana	18	6,483,802	3,605,206	2,826,874	378,472	376,055	376,006	374,020	362,970	426,104	426,104
Iowa	19	3,046,355	2,475,638	2,254,363	190,406	183,628	160,919	160,060	154,548	195,842	195,838
Kansas	20	2,853,118	1,604,917	1,482,882	144,571	143,487	142,357	141,908	137,455	168,676	168,676
Kentucky	21	4,339,367	2,273,871	2,046,845	178,704	163,195	163,177	162,474	157,307	192,435	192,388
Louisiana	22	4,533,372	2,008,829	1,529,756	98,598	95,843	95,207	94,086	93,534	108,933	108,918
Maine	23	6,547,629	719,227	460,020	44,623	43,848	43,478	42,951	42,563	49,312	49,312
Maryland	24	5,773,552	2,387,967	2,058,406	299,880	295,038	278,647	278,352	238,530	259,637	259,637
Massachusetts	25	1,328,361	2,328,876	1,942,199	141,901	141,479	139,866	139,637	139,188	150,320	150,320
Michigan	26	9,883,640	4,772,632	4,092,335	169,104	165,863	134,446	134,232	129,046	158,291	158,291
Minnesota	27	5,303,925	3,035,787	2,775,260	310,103	291,328	272,136	269,064	245,889	293,867	293,862
Mississippi	28	2,967,297	1,878,154	1,491,630	213,044	210,659	210,610	208,413	207,525	250,103	250,100
Missouri	29	5,988,927	3,035,310	2,740,471	311,058	286,472	282,531	279,224	271,983	328,621	328,607
Montana	30	989,415	924,399	694,686	89,552	89,033	89,033	87,845	85,483	109,585	109,585
Nebraska	31	1,826,341	1,124,735	1,031,853	112,671	111,787	110,320	109,942	106,612	127,463	127,463
Nevada	32	2,700,551	1,289,017	1,013,929	392,634	388,731	348,171	347,937	335,009	353,102	353,102
New Hampshire	33	1,316,470	614,126	493,762	71,622	71,031	68,187	67,283	66,472	77,561	77,561
New Jersey	34	8,791,894	3,442,800	3,033,158	285,267	272,767	269,746	269,375	237,151	244,922	244,922
New Mexico	35	2,059,179	1,562,402	816,004	110,882	103,230	102,430	102,071	98,887	108,389	108,382
New York	36	19,378,102	5,526,450	4,841,974	304,471	302,370	300,145	298,118	278,521	322,046	322,046
North Carolina	37	9,535,483	5,530,054	4,541,780	971,078	966,322	946,238	944,203	887,504	970,244	970,226
North Dakota	38	672,591	481,566	387,982	31,331	24,734	24,137	24,073	22,605	25,853	25,853
Ohio	39	11,536,504	6,226,336	5,074,631	503,486	500,616	485,261	484,004	453,196	531,592	531,592
Oklahoma	40	3,751,351	2,308,644	2,114,591	277,737	273,557	273,284	271,843	271,116	331,732	331,732

Table A1-1: CoreLogic Dataset Primary Filtering by State CoreLogic Dataset Primary Filtering by State (cont.)

State / District of Columbia	FIPS	State Population (Based on 2010 Census)	CoreLogic Raw Parcel Count	Level 1 Parcels Remove Parcels with Hazus Occupancies not evaluated (Vacant, Unknown, Blank)	Level 2 Parcels with Year Built > 1999 or Year Built = 0 and Effective Year Built > 1999	Level 3A Parcels with Square Footage ≥ 0	Level 3B Parcels Merge Stacked Parcels to Single Parcel Based on Land Use	Level 4 Parcels Parcels with Square Footage ≥ 500	Level 5 Parcels Merge COM and IND Parcels on Large Footprints	Level 6 Building Centroids Convert dataset from Parcels to Building Centroids and Merge Non-Symmetrical Stacked Parcels	Level 7 Building Centroids Filter out Counties with Less than 10 Building Centroids
Oregon	41	3,831,074	1,880,115	1,577,632	267,199	245,914	243,926	242,655	230,812	268,523	268,523
Pennsylvania	42	12,702,379	5,998,863	5,142,183	408,667	400,989	398,752	396,769	357,023	404,509	404,483
Rhode Island	44	1,052,567	331,652	281,416	20,139	20,121	18,814	18,792	18,678	20,743	20,743
South Carolina	45	4,625,364	2,676,688	2,249,609	451,924	436,216	408,405	406,984	395,038	429,591	429,580
South Dakota	46	814,180	566,606	345,640	39,521	35,528	35,263	35,109	33,903	40,665	40,665
Tennessee	47	6,346,105	3,314,943	3,193,579	537,450	524,829	518,935	516,725	501,518	577,340	577,340
Texas	48	25,145,561	12,335,154	9,362,994	2,409,749	2,327,920	2,317,094	2,301,171	2,281,589	2,539,040	2,539,003
Utah	49	2,763,885	1,395,562	1,049,459	264,743	263,699	259,723	258,494	242,556	256,634	256,631
Vermont	50	625,741	325,586	228,998	12,457	12,328	12,175	11,978	11,891	14,353	14,353
Virginia	51	8,001,024	4,007,021	3,589,244	516,782	504,676	490,279	489,247	440,707	480,384	480,340
Washington	53	6,724,540	3,302,488	2,855,115	533,500	528,094	492,444	488,214	470,281	553,027	553,027
West Virginia	54	1,852,994	1,469,933	1,054,181	90,016	89,943	88,640	87,540	84,686	98,870	98,870
Wisconsin	55	5,686,986	3,650,625	3,323,759	68,470	66,423	37,836	37,773	36,756	42,023	42,023
Wyoming	56	563,626	386,991	284,180	48,762	48,480	48,443	47,594	45,035	58,827	58,827
Total		**308,759,015**	**146,881,502**	**122,811,145**	**18,092,524**	**17,702,913**	**17,033,047**	**16,948,439**	**16,177,615**	**18,172,384**	**18,172,122**

Table A1-2a: CoreLogic Key Data Population Percent by State and FEMA Region

State	State FIPS	Level 7 Building Count	Land Use		Basement Finish		Building Code		Construction Type		Exterior Walls		Foundation		Frame		Garage	
			#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Alabama	01	374,443	374,443	100%	6,974	2%	349,229	93%	2	0%	342,812	92%	294,019	79%	10,061	3%	119,012	32%
Alaska	02	41,492	41,492	100%	2,827	7%	38,866	94%	15,712	38%	15,587	38%	14,941	36%	0	0%	15,938	38%
Arizona	04	751,206	751,206	100%	1,202	0%	738,658	98%	270,295	36%	619,992	83%	81,287	11%	1,221	0%	199,767	27%
Arkansas	05	222,661	222,661	100%	6,004	3%	218,333	98%	83,254	37%	191,348	86%	202,843	91%	87	0%	179,206	80%
California	06	1,388,971	1,388,971	100%	1,909	0%	198,563	14%	728,138	52%	19,571	1%	25,506	2%	39,961	3%	551,171	40%
Colorado	08	458,424	458,424	100%	127,714	28%	380,949	83%	163,464	36%	379,949	83%	146,836	32%	65,230	14%	364,012	79%
Connecticut	09	85,483	85,483	100%	0	0%	0	0%	26,688	31%	80,401	94%	0	0%	0	0%	28,413	33%
Delaware	10	77,264	77,264	100%	9,954	13%	20,362	26%	27,082	35%	75,425	98%	37,982	49%	152	0%	65,194	84%
District of Columbia	11	4,762	4,762	100%	41	1%	4,762	100%	822	17%	4,532	95%	0	0%	0	0%	64	1%
Florida	12	1,775,701	1,775,701	100%	494	0%	1,244,729	70%	645,790	36%	1,481,179	83%	668,529	38%	389,962	22%	1,262,127	71%
Georgia	13	923,382	923,382	100%	80,591	9%	705,205	76%	48,091	5%	850,503	92%	574,196	62%	152,045	16%	460,570	50%
Hawaii	15	54,402	54,402	100%	4,626	9%	45,273	83%	9,013	17%	45,980	85%	51,160	94%	25,744	47%	46,491	85%
Idaho	16	183,208	183,208	100%	18,224	10%	162,940	89%	34,542	19%	52,637	29%	43,703	24%	35,263	19%	143,966	79%
Illinois	17	261,798	261,798	100%	85,811	33%	99,474	38%	19,877	8%	159,300	61%	22,546	9%	3,828	1%	181,392	69%
Indiana	18	426,104	426,104	100%	80,493	19%	421,867	99%	286,576	67%	16,741	4%	4,108	1%	245	0%	352,997	83%
Iowa	19	195,838	195,838	100%	69,892	36%	162,701	83%	92,740	47%	168,574	86%	158,440	81%	1,969	1%	153,076	78%
Kansas	20	168,676	168,676	100%	41,401	25%	91,361	54%	2,671	2%	145,897	86%	139,119	82%	0	0%	144,599	86%
Kentucky	21	192,388	192,388	100%	28,992	15%	126,595	66%	53,704	28%	163,495	85%	120,966	63%	4	0%	127,452	66%
Louisiana	22	108,918	108,918	100%	3	0%	93,692	86%	4,076	4%	687	1%	3,844	4%	0	0%	13,277	12%
Maine	23	49,312	49,312	100%	0	0%	0	0%	13,593	28%	38,349	78%	0	0%	0	0%	4,963	10%
Maryland	24	259,637	259,637	100%	76,087	29%	259,387	100%	10,854	4%	251,662	97%	3,981	2%	0	0%	210,532	81%
Massachusetts	25	150,320	150,320	100%	0	0%	0	0%	83,194	55%	144,705	96%	0	0%	0	0%	42,913	29%
Michigan	26	158,291	158,291	100%	26,891	17%	7,577	5%	16,000	10%	109,681	69%	5,434	3%	1,583	1%	87,833	55%
Minnesota	27	293,862	293,862	100%	80,657	27%	157,634	54%	107,103	36%	207,130	70%	138,315	47%	72,451	25%	163,073	55%
Mississippi	28	250,100	250,100	100%	252	0%	249,806	100%	23,269	9%	195,561	78%	194,268	78%	0	0%	30,048	12%
Missouri	29	328,607	328,607	100%	46,010	14%	147,884	45%	78,682	24%	175,846	54%	91,047	28%	7,420	2%	107,717	33%
Montana	30	109,585	109,585	100%	18,604	17%	109,535	100%	77,215	70%	101,570	93%	100,133	91%	812	1%	83,484	76%
Nebraska	31	127,463	127,463	100%	67,737	53%	54,208	43%	773	1%	91,513	72%	62,987	49%	4,454	3%	111,924	88%
Nevada	32	353,102	353,102	100%	4,268	1%	90,753	26%	59,177	17%	323,733	92%	96,950	27%	0	0%	323,433	92%
New Hampshire	33	77,561	77,561	100%	0	0%	0	0%	12,675	16%	75,222	97%	0	0%	0	0%	15,478	20%
New Jersey	34	244,922	244,922	100%	0	0%	49,842	20%	912	0%	134,700	55%	43,524	18%	0	0%	72,319	30%
New Mexico	35	108,382	108,382	100%	128	0%	34,148	32%	5,288	5%	21,058	19%	4	0%	163	0%	20,283	19%
New York	36	322,046	322,046	100%	459	0%	44,818	14%	0	0%	256,326	80%	0	0%	0	0%	203,303	63%
North Carolina	37	970,226	970,226	100%	34,786	4%	729,127	75%	70,564	7%	849,520	88%	601,876	62%	36,912	4%	503,139	52%
North Dakota	38	25,853	25,853	100%	2,927	11%	15,011	58%	2,541	10%	9,368	36%	9,564	37%	0	0%	12,137	47%
Ohio	39	531,592	531,592	100%	71,491	13%	204,691	39%	102,322	19%	433,174	81%	36,108	7%	20,771	4%	401,639	76%
Oklahoma	40	331,732	331,732	100%	2,101	1%	304,952	92%	19,789	6%	314,810	95%	254,179	77%	6,494	2%	246,514	74%
Oregon	41	268,523	268,523	100%	8,127	3%	228,063	85%	43,929	16%	122,298	46%	118,936	44%	2,772	1%	180,759	67%
Pennsylvania	42	404,483	404,483	100%	16,497	4%	84,867	21%	23,613	6%	332,363	82%	14,207	4%	9	0%	181,997	45%

Table A1-2a: CoreLogic Key Data Population Percent by State and FEMA Region (cont.)

State	State FIPS	Level 7 Building Count	Land Use		Basement Finish		Building Code		Construction Type		Exterior Walls		Foundation		Frame		Garage	
			#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Rhode Island	44	20,743	20,743	100%	0	0%	0	0%	4,696	23%	19,875	96%	0	0%	0	0%	5,723	28%
South Carolina	45	429,580	429,580	100%	9,441	2%	183,171	43%	0	0%	183,397	43%	128,924	30%	47,854	11%	211,841	49%
South Dakota	46	40,665	40,665	100%	18,458	45%	33,222	82%	1,164	3%	17,358	43%	14,987	37%	14,928	37%	28,772	71%
Tennessee	47	577,340	577,340	100%	26,911	5%	476,055	82%	2,153	0%	485,276	84%	404,697	70%	233,283	40%	381,825	66%
Texas	48	2,539,003	2,539,003	100%	1,826	0%	1,834,547	72%	315,655	12%	1,748,313	69%	1,888,181	74%	1,995	0%	1,705,017	67%
Utah	49	256,631	256,631	100%	59,474	23%	145,004	57%	26,868	10%	201,840	79%	60,383	24%	0	0%	154,875	60%
Vermont	50	14,353	14,353	100%	2,059	14%	11,561	81%	3,132	22%	13,239	92%	0	0%	0	0%	2,598	18%
Virginia	51	480,340	480,340	100%	114,831	24%	294,236	61%	156,163	33%	445,716	93%	279,051	58%	15,977	3%	306,039	64%
Washington	53	553,027	553,027	100%	45,433	8%	428,565	77%	109,159	20%	392,804	71%	223,933	40%	2,330	0%	450,652	81%
West Virginia	54	98,870	98,870	100%	16,611	17%	203	0%	54	0%	94,576	96%	22	0%	0	0%	9,017	9%
Wisconsin	55	42,023	42,023	100%	8,458	20%	17,992	43%	0	0%	37,464	89%	9,506	23%	1,173	3%	31,898	76%
Wyoming	56	58,827	58,827	100%	14,016	24%	41,986	71%	0	0%	53,499	91%	12,129	21%	0	0%	35,755	61%
Total		**18,172,122**	**18,172,122**	**100%**	**1,341,692**	**7%**	**11,342,404**	**62%**	**3,883,074**	**21%**	**12,696,556**	**70%**	**7,383,351**	**41%**	**1,197,153**	**7%**	**10,736,224**	**59%**

Table A1-2b: CoreLogic Key Data Population Percent by State and FEMA Region

State	State FIPS	Level 7 Building Count	Roof Cover		Roof Type		Story Number		Number of Buildings		Units Number		Year Built (valid year)		Square Footage	
			#	%	#	%	#	%	#	%	#	%	#	%	#	%
Alabama	01	374,443	326,767	87%	350,093	93%	309,864	83%	374,443	100%	10,710	3%	374,443	100%	374,443	100%
Alaska	02	41,492	393	1%	476	1%	28,884	70%	41,492	100%	9,899	24%	41,492	100%	41,492	100%
Arizona	04	751,206	681,226	91%	683,442	91%	735,205	98%	751,206	100%	27,960	4%	751,206	100%	751,206	100%
Arkansas	05	222,661	177,280	80%	204,829	92%	222,524	100%	222,661	100%	1,400	1%	222,661	100%	222,661	100%
California	06	1,388,971	433,510	31%	434,689	31%	945,870	68%	1,388,971	100%	288,492	21%	1,388,971	100%	1,388,971	100%
Colorado	08	458,424	346,310	76%	383,206	84%	408,984	89%	458,424	100%	70,387	15%	458,424	100%	458,424	100%
Connecticut	09	85,483	74,660	87%	74,908	88%	84,012	98%	85,483	100%	74,331	87%	85,483	100%	85,483	100%
Delaware	10	77,264	57,207	74%	57,287	74%	67,090	87%	77,264	100%	1,434	2%	77,264	100%	77,264	100%
District of Columbia	11	4,762	4,017	84%	4,118	86%	4,685	98%	4,762	100%	4,405	93%	4,762	100%	4,762	100%
Florida	12	1,775,701	1,437,184	81%	1,493,393	84%	1,574,804	89%	1,775,701	100%	817,722	46%	1,775,701	100%	1,775,701	100%
Georgia	13	923,382	625,237	68%	693,891	75%	845,363	92%	923,382	100%	73,935	8%	923,382	100%	923,382	100%
Hawaii	15	54,402	51,091	94%	51,693	95%	52,087	96%	54,402	100%	30,409	56%	54,402	100%	54,402	100%
Idaho	16	183,208	66,226	36%	72,185	39%	110,597	60%	183,208	100%	5,463	3%	183,208	100%	183,208	100%
Illinois	17	261,798	62,808	24%	65,764	25%	217,941	83%	261,798	100%	13,228	5%	261,798	100%	261,798	100%
Indiana	18	426,104	343,431	81%	343,802	81%	396,230	93%	426,104	100%	9,541	2%	426,104	100%	426,104	100%
Iowa	19	195,838	135,701	69%	163,515	83%	158,927	81%	195,838	100%	9,571	5%	195,838	100%	195,838	100%
Kansas	20	168,676	143,428	85%	143,428	85%	140,868	84%	168,676	100%	79,020	47%	168,676	100%	168,676	100%
Kentucky	21	192,388	107,417	56%	130,077	68%	166,593	87%	192,388	100%	3,401	2%	192,388	100%	192,388	100%
Louisiana	22	108,918	1,379	1%	1,414	1%	4,104	4%	108,918	100%	2,215	2%	108,918	100%	108,918	100%
Maine	23	49,312	38,906	79%	38,949	79%	42,711	87%	49,312	100%	37,303	76%	49,312	100%	49,312	100%
Maryland	24	259,637	242,259	93%	245,386	95%	248,084	96%	259,637	100%	13,316	5%	259,637	100%	259,637	100%
Massachusetts	25	150,320	130,656	87%	140,282	93%	148,655	99%	150,320	100%	128,325	85%	150,320	100%	150,320	100%
Michigan	26	158,291	35,734	23%	48,033	30%	131,430	83%	158,291	100%	45,174	29%	158,291	100%	158,291	100%
Minnesota	27	293,862	169,611	58%	211,793	72%	152,118	52%	293,862	100%	35,667	12%	293,862	100%	293,862	100%
Mississippi	28	250,100	181,382	73%	189,537	76%	100,288	40%	250,100	100%	3,901	2%	250,100	100%	250,100	100%
Missouri	29	328,607	95,208	29%	104,429	32%	203,152	62%	328,607	100%	33,075	10%	328,607	100%	328,607	100%
Montana	30	109,585	81,580	74%	100,659	92%	104,115	95%	109,585	100%	11,158	10%	109,585	100%	109,585	100%
Nebraska	31	127,463	91,438	72%	95,300	75%	120,583	95%	127,463	100%	37,327	29%	127,463	100%	127,463	100%
Nevada	32	353,102	308,271	87%	311,321	88%	347,885	99%	353,102	100%	66,117	19%	353,102	100%	353,102	100%
New Hampshire	33	77,561	72,824	94%	72,854	94%	77,039	99%	77,561	100%	45,481	59%	77,561	100%	77,561	100%
New Jersey	34	244,922	46,357	19%	46,646	19%	140,942	58%	244,922	100%	11,198	5%	244,922	100%	244,922	100%
New Mexico	35	108,382	22,333	21%	41,981	39%	34,544	32%	108,382	100%	3,739	3%	108,382	100%	108,382	100%
New York	36	322,046	382	0%	382	0%	299,971	93%	322,046	100%	51,102	16%	322,046	100%	322,046	100%
North Carolina	37	970,226	531,965	55%	618,061	64%	899,619	93%	970,226	100%	273,472	28%	970,226	100%	970,226	100%
North Dakota	38	25,853	8,240	32%	9,521	37%	14,743	57%	25,853	100%	2,134	8%	25,853	100%	25,853	100%
Ohio	39	531,592	91,218	17%	93,851	18%	496,035	93%	531,592	100%	61,560	12%	531,592	100%	531,592	100%
Oklahoma	40	331,732	288,909	87%	328,680	99%	302,426	91%	331,732	100%	10,953	3%	331,732	100%	331,732	100%
Oregon	41	268,523	162,067	60%	167,208	62%	162,025	60%	268,523	100%	13,813	5%	268,523	100%	268,523	100%
Pennsylvania	42	404,483	76,423	19%	78,800	19%	346,303	86%	404,483	100%	51,160	13%	404,483	100%	404,483	100%

Table A1-2b: CoreLogic Key Data Population Percent by State and FEMA Region (cont.)

State	State FIPS	Level 7 Building Count	Roof Cover		Roof Type		Story Number		Number of Buildings		Units Number		Year Built (valid year)		Square Footage	
			#	%	#	%	#	%	#	%	#	%	#	%	#	%
Rhode Island	44	20,743	20,540	99%	20,575	99%	20,665	100%	20,743	100%	20,370	98%	20,743	100%	20,743	100%
South Carolina	45	429,580	170,542	40%	174,683	41%	299,839	70%	429,580	100%	11,562	3%	429,580	100%	429,580	100%
South Dakota	46	40,665	21,392	53%	23,233	57%	9,249	23%	40,665	100%	3,043	7%	40,665	100%	40,665	100%
Tennessee	47	577,340	432,055	75%	433,801	75%	505,802	88%	577,340	100%	171,516	30%	577,340	100%	577,340	100%
Texas	48	2,539,003	1,197,826	47%	1,406,686	55%	1,780,498	70%	2,539,003	100%	91,925	4%	2,539,003	100%	2,539,003	100%
Utah	49	256,631	195,132	76%	200,672	78%	218,953	85%	256,631	100%	38,924	15%	256,631	100%	256,631	100%
Vermont	50	14,353	9,854	69%	11,802	82%	9,221	64%	14,353	100%	1,141	8%	14,353	100%	14,353	100%
Virginia	51	480,340	409,854	85%	432,070	90%	465,032	97%	480,340	100%	33,539	7%	480,340	100%	480,340	100%
Washington	53	553,027	404,102	73%	419,160	76%	505,454	91%	553,027	100%	116,832	21%	553,027	100%	553,027	100%
West Virginia	54	98,870	23	0%	23	0%	98,696	100%	98,870	100%	90,200	91%	98,870	100%	98,870	100%
Wisconsin	55	42,023	13,185	31%	13,890	33%	37,334	89%	42,023	100%	19,130	46%	42,023	100%	42,023	100%
Wyoming	56	58,827	46,855	80%	58,571	100%	56,938	97%	58,827	100%	8,898	15%	58,827	100%	58,827	100%
	Total	**18,172,122**	**10,672,395**	**59%**	**11,491,049**	**63%**	**14,854,981**	**82%**	**18,172,122**	**100%**	**3,076,578**	**17%**	**18,172,122**	**100%**	**18,172,122**	**100%**

Table A1-2c: CoreLogic Key Data Population Percent by State and FEMA Region

State	State FIPS	Level 7 Building Count	Calculated Hazus Occupancy		State FIPS Code		County FIPS Code		Census Tract		Census Block		Building Replacement Value		Content Replacement Value	
			#	%	#	%	#	%	#	%	#	%	#	%	#	%
Alabama	01	374,443	374,443	100%	374,443	100%	374,443	100%	374,443	100%	374,443	100%	374,443	100%	374,443	100%
Alaska	02	41,492	41,492	100%	41,492	100%	41,492	100%	41,492	100%	41,492	100%	41,492	100%	41,492	100%
Arizona	04	751,206	751,206	100%	751,206	100%	751,206	100%	751,206	100%	751,206	100%	751,206	100%	751,206	100%
Arkansas	05	222,661	222,661	100%	222,661	100%	222,661	100%	222,661	100%	222,661	100%	222,661	100%	222,661	100%
California	06	1,388,971	1,388,971	100%	1,388,971	100%	1,388,971	100%	1,388,971	100%	1,388,971	100%	1,388,971	100%	1,388,971	100%
Colorado	08	458,424	458,424	100%	458,424	100%	458,424	100%	458,424	100%	458,424	100%	458,424	100%	458,424	100%
Connecticut	09	85,483	85,483	100%	85,483	100%	85,483	100%	85,483	100%	85,483	100%	85,483	100%	85,483	100%
Delaware	10	77,264	77,264	100%	77,264	100%	77,264	100%	77,264	100%	77,264	100%	77,264	100%	77,264	100%
District of Columbia	11	4,762	4,762	100%	4,762	100%	4,762	100%	4,762	100%	4,762	100%	4,762	100%	4,762	100%
Florida	12	1,775,701	1,775,701	100%	1,775,701	100%	1,775,701	100%	1,775,701	100%	1,775,701	100%	1,775,701	100%	1,775,701	100%
Georgia	13	923,382	923,382	100%	923,382	100%	923,382	100%	923,382	100%	923,382	100%	923,382	100%	923,382	100%
Hawaii	15	54,402	54,402	100%	54,402	100%	54,402	100%	54,402	100%	54,402	100%	54,402	100%	54,402	100%
Idaho	16	183,208	183,208	100%	183,208	100%	183,208	100%	183,208	100%	183,208	100%	183,208	100%	183,208	100%
Illinois	17	261,798	261,798	100%	261,798	100%	261,798	100%	261,798	100%	261,798	100%	261,798	100%	261,798	100%
Indiana	18	426,104	426,104	100%	426,104	100%	426,104	100%	426,104	100%	426,104	100%	426,104	100%	426,104	100%
Iowa	19	195,838	195,838	100%	195,838	100%	195,838	100%	195,838	100%	195,838	100%	195,838	100%	195,838	100%
Kansas	20	168,676	168,676	100%	168,676	100%	168,676	100%	168,676	100%	168,676	100%	168,676	100%	168,676	100%
Kentucky	21	192,388	192,388	100%	192,388	100%	192,388	100%	192,388	100%	192,388	100%	192,388	100%	192,388	100%
Louisiana	22	108,918	108,918	100%	108,918	100%	108,918	100%	108,918	100%	108,918	100%	108,918	100%	108,918	100%
Maine	23	49,312	49,312	100%	49,312	100%	49,312	100%	49,312	100%	49,312	100%	49,312	100%	49,312	100%
Maryland	24	259,637	259,637	100%	259,637	100%	259,637	100%	259,637	100%	259,637	100%	259,637	100%	259,637	100%
Massachusetts	25	150,320	150,320	100%	150,320	100%	150,320	100%	150,320	100%	150,320	100%	150,320	100%	150,320	100%
Michigan	26	158,291	158,291	100%	158,291	100%	158,291	100%	158,291	100%	158,291	100%	158,291	100%	158,291	100%
Minnesota	27	293,862	293,862	100%	293,862	100%	293,862	100%	293,862	100%	293,862	100%	293,862	100%	293,862	100%
Mississippi	28	250,100	250,100	100%	250,100	100%	250,100	100%	250,100	100%	250,100	100%	250,100	100%	250,100	100%
Missouri	29	328,607	328,607	100%	328,607	100%	328,607	100%	328,607	100%	328,607	100%	328,607	100%	328,607	100%
Montana	30	109,585	109,585	100%	109,585	100%	109,585	100%	109,585	100%	109,585	100%	109,585	100%	109,585	100%
Nebraska	31	127,463	127,463	100%	127,463	100%	127,463	100%	127,463	100%	127,463	100%	127,463	100%	127,463	100%
Nevada	32	353,102	353,102	100%	353,102	100%	353,102	100%	353,102	100%	353,102	100%	353,102	100%	353,102	100%
New Hampshire	33	77,561	77,561	100%	77,561	100%	77,561	100%	77,561	100%	77,561	100%	77,561	100%	77,561	100%
New Jersey	34	244,922	244,922	100%	244,922	100%	244,922	100%	244,922	100%	244,922	100%	244,922	100%	244,922	100%
New Mexico	35	108,382	108,382	100%	108,382	100%	108,382	100%	108,382	100%	108,382	100%	108,382	100%	108,382	100%
New York	36	322,046	322,046	100%	322,046	100%	322,046	100%	322,046	100%	322,046	100%	322,046	100%	322,046	100%
North Carolina	37	970,226	970,226	100%	970,226	100%	970,226	100%	970,226	100%	970,226	100%	970,226	100%	970,226	100%
North Dakota	38	25,853	25,853	100%	25,853	100%	25,853	100%	25,853	100%	25,853	100%	25,853	100%	25,853	100%
Ohio	39	531,592	531,592	100%	531,592	100%	531,592	100%	531,592	100%	531,592	100%	531,592	100%	531,592	100%
Oklahoma	40	331,732	331,732	100%	331,732	100%	331,732	100%	331,732	100%	331,732	100%	331,732	100%	331,732	100%
Oregon	41	268,523	268,523	100%	268,523	100%	268,523	100%	268,523	100%	268,523	100%	268,523	100%	268,523	100%

Table A1-2c: CoreLogic Key Data Population Percent by State and FEMA Region (cont.)

State	State FIPS	Level 7 Building Count	Calculated Hazus Occupancy		State FIPS Code		County FIPS Code		Census Tract		Census Block		Building Replacement Value		Content Replacement Value	
			#	%	#	%	#	%	#	%	#	%	#	%	#	%
Pennsylvania	42	404,483	404,483	100%	404,483	100%	404,483	100%	404,483	100%	404,483	100%	404,483	100%	404,483	100%
Rhode Island	44	20,743	20,743	100%	20,743	100%	20,743	100%	20,743	100%	20,743	100%	20,743	100%	20,743	100%
South Carolina	45	429,580	429,580	100%	429,580	100%	429,580	100%	429,580	100%	429,580	100%	429,580	100%	429,580	100%
South Dakota	46	40,665	40,665	100%	40,665	100%	40,665	100%	40,665	100%	40,665	100%	40,665	100%	40,665	100%
Tennessee	47	577,340	577,340	100%	577,340	100%	577,340	100%	577,340	100%	577,340	100%	577,340	100%	577,340	100%
Texas	48	2,539,003	2,539,003	100%	2,539,003	100%	2,539,003	100%	2,539,003	100%	2,539,003	100%	2,539,003	100%	2,539,003	100%
Utah	49	256,631	256,631	100%	256,631	100%	256,631	100%	256,631	100%	256,631	100%	256,631	100%	256,631	100%
Vermont	50	14,353	14,353	100%	14,353	100%	14,353	100%	14,353	100%	14,353	100%	14,353	100%	14,353	100%
Virginia	51	480,340	480,340	100%	480,340	100%	480,340	100%	480,340	100%	480,340	100%	480,340	100%	480,340	100%
Washington	53	553,027	553,027	100%	553,027	100%	553,027	100%	553,027	100%	553,027	100%	553,027	100%	553,027	100%
West Virginia	54	98,870	98,870	100%	98,870	100%	98,870	100%	98,870	100%	98,870	100%	98,870	100%	98,870	100%
Wisconsin	55	42,023	42,023	100%	42,023	100%	42,023	100%	42,023	100%	42,023	100%	42,023	100%	42,023	100%
Wyoming	56	58,827	58,827	100%	58,827	100%	58,827	100%	58,827	100%	58,827	100%	58,827	100%	58,827	100%
	Total	**18,172,122**	**18,172,122**	**100%**	**18,172,122**	**100%**	**18,172,122**	**100%**	**18,172,122**	**100%**	**18,172,122**	**100%**	**18,172,122**	**100%**	**18,172,122**	**100%**

Table A1-3: CoreLogic Key Data Population Percent by County

The following CoreLogic data summary tables, Table A1-3, is in an Excel file that is available at the Building Codes Save website: https://www.fema.gov/emergency-managers/risk-management/building-science/building-codes-save-study.

A.2 AALA Results Tables

The following results tables are in an Excel file that is available at the Building Codes Save website: https://www.fema.gov/emergency-managers/risk-management/building-science/building-codes-save-study. The data in the Excel file may be sorted.

Tables A2-1, A2-2, and A2-3 are also provided in Chapters 4, 5, and 6 of the main BCS Study report.

Table A2-1: AALA by County: Florida Results including SF, BRV, and CRV

Table A2-2: AALA by County: California Results including SF, BRV, and CRV

Table A2-3: AALA Occ CA, FL: Florida and California Results by Occupancy

Table A2-4: AALA by State: Nationwide Results by State with SF, BRV, CRV

Table A2-5: AALA Occ by State: Nationwide Results by State and Occupancy

Table A2-6: AALA Occ by County: Nationwide Results by County with SF, BRV, and CRV

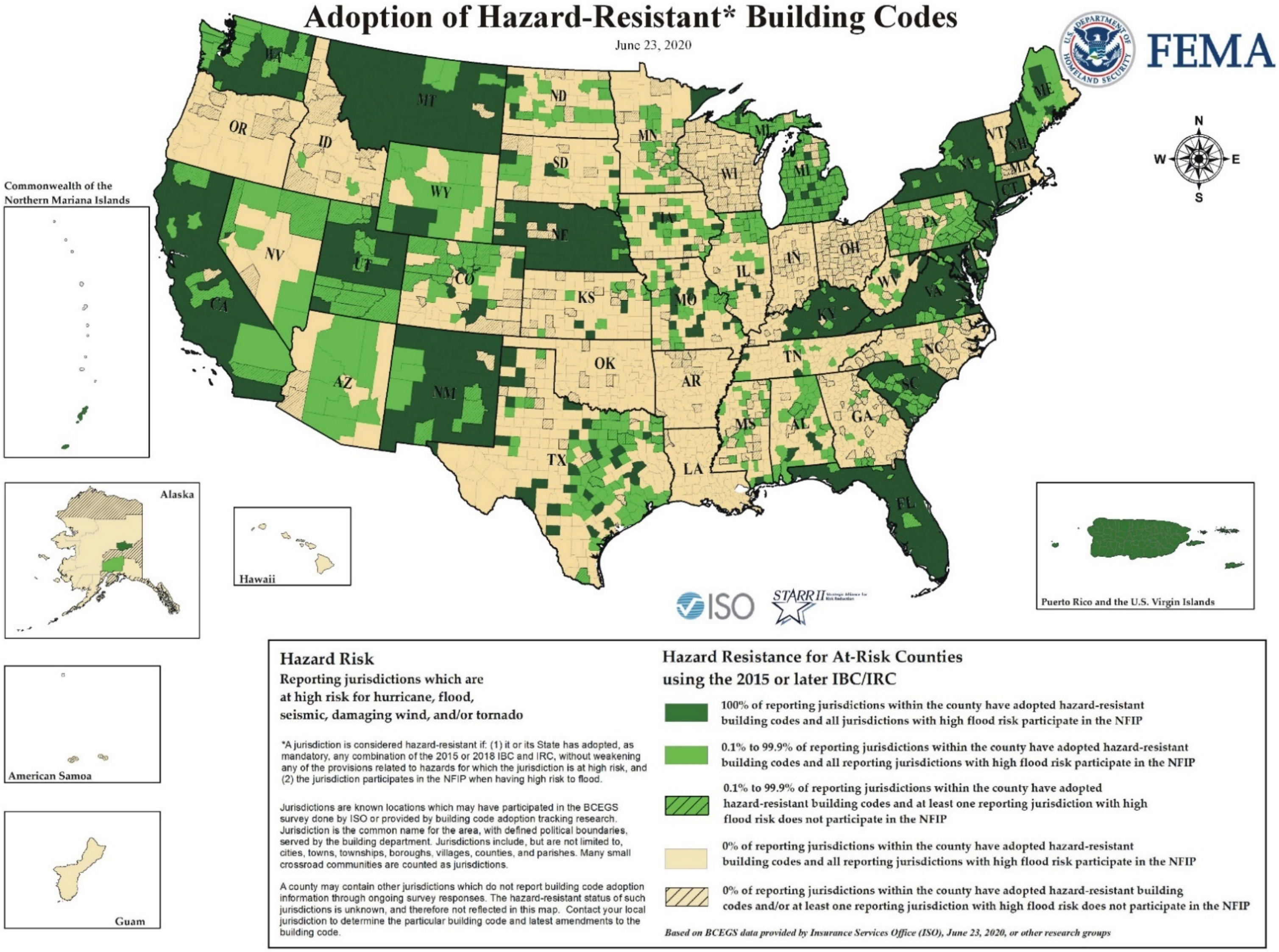
Table A2-7: AALA Occ by County: Nationwide Results by County and Occupancy

Table A2-8: AALA Pos-Neg: Nationwide Results by State with Positive, Negative, and Neutral Losses Avoided

APPENDIX B:
Building Code Data

B.1 ISO BCEGS Maps

The following maps are current versions of nationwide code adoption by hazard provisions. The maps were produced by FEMA using ISO BCEGS code-adoption tracking data.



Hazard Risk

Reporting jurisdictions which are at high risk for hurricane, flood, seismic, damaging wind, and/or tornado

*A jurisdiction is considered hazard-resistant if: (1) it or its State has adopted, as mandatory, any combination of the 2015 or 2018 IBC and IRC, without weakening any of the provisions related to hazards for which the jurisdiction is at high risk, and (2) the jurisdiction participates in the NFIP when having high risk to flood.

Jurisdictions are known locations which may have participated in the BCEGS survey done by ISO or provided by building code adoption tracking research. Jurisdiction is the common name for the area, with defined political boundaries, served by the building department. Jurisdictions include, but are not limited to, cities, towns, townships, boroughs, villages, counties, and parishes. Many small crossroad communities are counted as jurisdictions.

A county may contain other jurisdictions which do not report building code adoption information through ongoing survey responses. The hazard-resistant status of such jurisdictions is unknown, and therefore not reflected in this map. Contact your local jurisdiction to determine the particular building code and latest amendments to the building code.

Hazard Resistance for At-Risk Counties using the 2015 or later IBC/IRC

🟩 100% of reporting jurisdictions within the county have adopted hazard-resistant building codes and all jurisdictions with high flood risk participate in the NFIP

🟩 0.1% to 99.9% of reporting jurisdictions within the county have adopted hazard-resistant building codes and all reporting jurisdictions with high flood risk participate in the NFIP

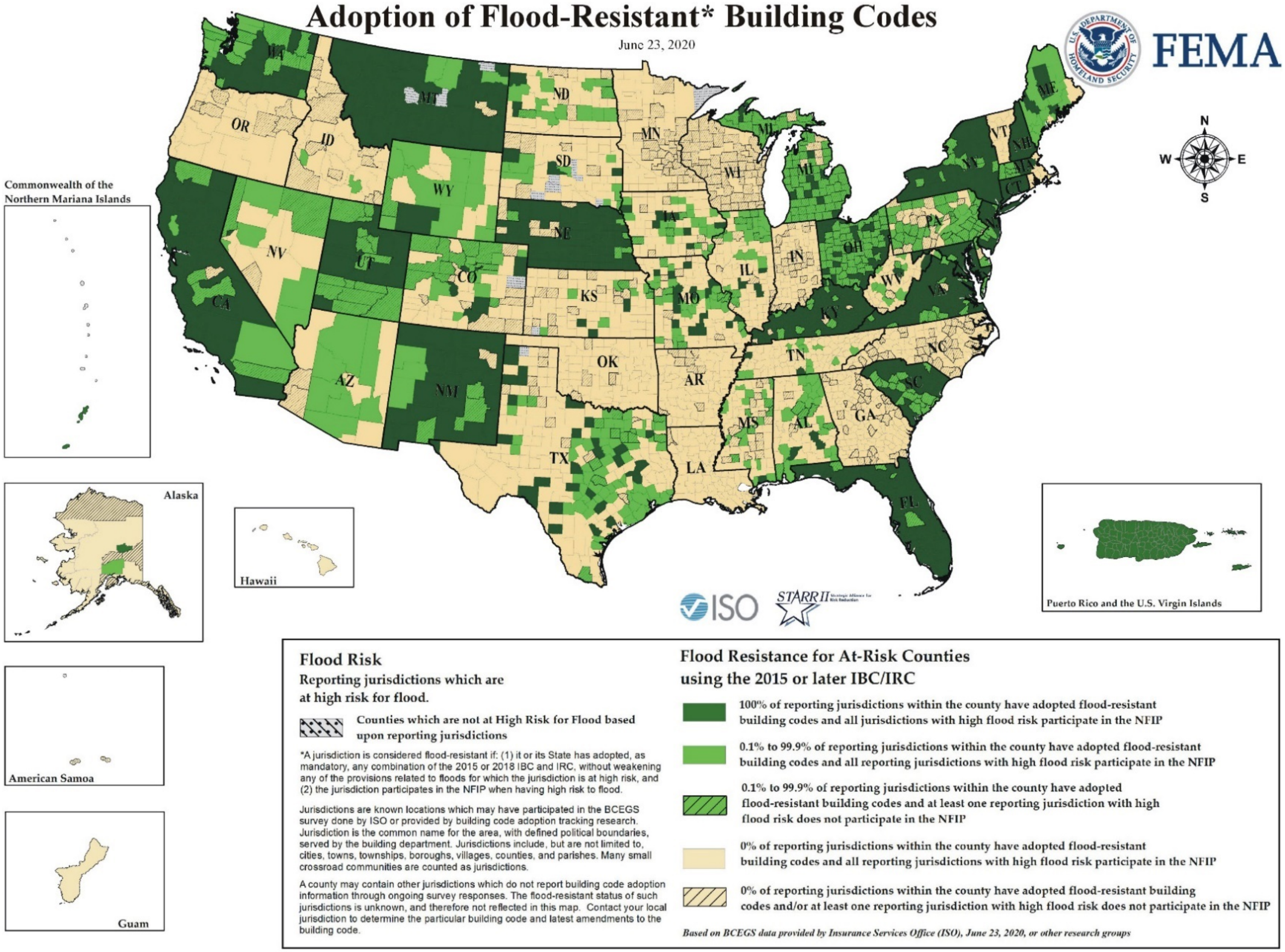
▨ 0.1% to 99.9% of reporting jurisdictions within the county have adopted hazard-resistant building codes and at least one reporting jurisdiction with high flood risk does not participate in the NFIP

🟨 0% of reporting jurisdictions within the county have adopted hazard-resistant building codes and all reporting jurisdictions with high flood risk participate in the NFIP

▨ 0% of reporting jurisdictions within the county have adopted hazard-resistant building codes and/or at least one reporting jurisdiction with high flood risk does not participate in the NFIP

Based on BCEGS data provided by Insurance Services Office (ISO), June 23, 2020, or other research groups

Figure B-1: Adoption of hazard-resistant building codes



Adoption of Flood-Resistant* Building Codes

June 23, 2020

Flood Risk

Reporting jurisdictions which are at high risk for flood.

▨ Counties which are not at High Risk for Flood based upon reporting jurisdictions

*A jurisdiction is considered flood-resistant if: (1) it or its State has adopted, as mandatory, any combination of the 2015 or 2018 IBC and IRC, without weakening any of the provisions related to floods for which the jurisdiction is at high risk, and (2) the jurisdiction participates in the NFIP when having high risk to flood.

Jurisdictions are known locations which may have participated in the BCEGS survey done by ISO or provided by building code adoption tracking research. Jurisdiction is the common name for the area, with defined political boundaries, served by the building department. Jurisdictions include, but are not limited to, cities, towns, townships, boroughs, villages, counties, and parishes. Many small crossroad communities are counted as jurisdictions.

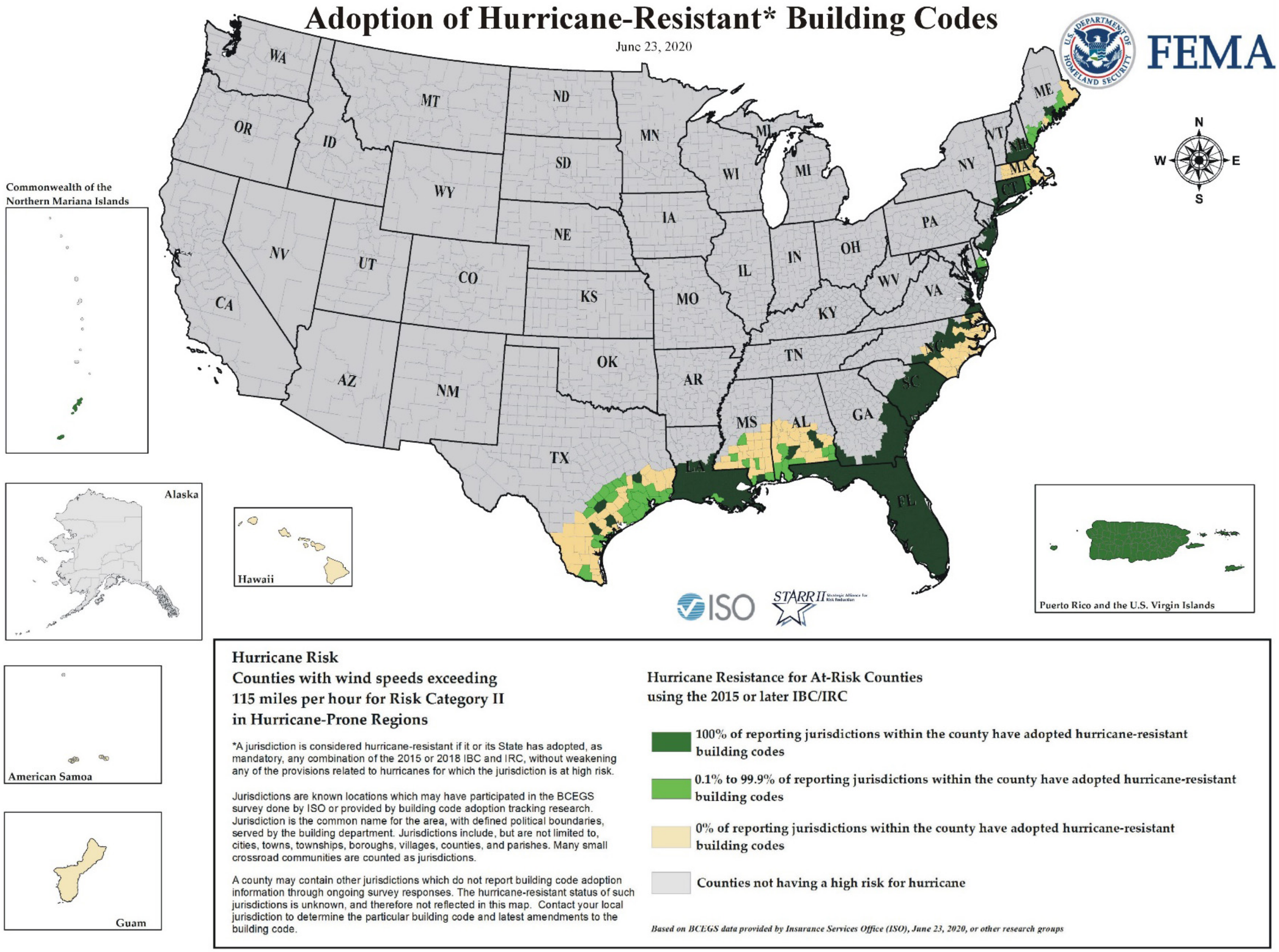
A county may contain other jurisdictions which do not report building code adoption information through ongoing survey responses. The flood-resistant status of such jurisdictions is unknown, and therefore not reflected in this map. Contact your local jurisdiction to determine the particular building code and latest amendments to the building code.

Flood Resistance for At-Risk Counties using the 2015 or later IBC/IRC

- 🟩 100% of reporting jurisdictions within the county have adopted flood-resistant building codes and all jurisdictions with high flood risk participate in the NFIP
- 🟩 0.1% to 99.9% of reporting jurisdictions within the county have adopted flood-resistant building codes and all reporting jurisdictions with high flood risk participate in the NFIP
- ▨ 0.1% to 99.9% of reporting jurisdictions within the county have adopted flood-resistant building codes and at least one reporting jurisdiction with high flood risk does not participate in the NFIP
- 🟨 0% of reporting jurisdictions within the county have adopted flood-resistant building codes and all reporting jurisdictions with high flood risk participate in the NFIP
- ▨ 0% of reporting jurisdictions within the county have adopted flood-resistant building codes and/or at least one reporting jurisdiction with high flood risk does not participate in the NFIP

Based on BCEGS data provided by Insurance Services Office (ISO), June 23, 2020, or other research groups

Figure B-2: Adoption of flood-resistant building codes



Adoption of Hurricane-Resistant* Building Codes

June 23, 2020

Hurricane Risk

Counties with wind speeds exceeding 115 miles per hour for Risk Category II in Hurricane-Prone Regions

*A jurisdiction is considered hurricane-resistant if it or its State has adopted, as mandatory, any combination of the 2015 or 2018 IBC and IRC, without weakening any of the provisions related to hurricanes for which the jurisdiction is at high risk.

Jurisdictions are known locations which may have participated in the BCEGS survey done by ISO or provided by building code adoption tracking research. Jurisdiction is the common name for the area, with defined political boundaries, served by the building department. Jurisdictions include, but are not limited to, cities, towns, townships, boroughs, villages, counties, and parishes. Many small crossroad communities are counted as jurisdictions.

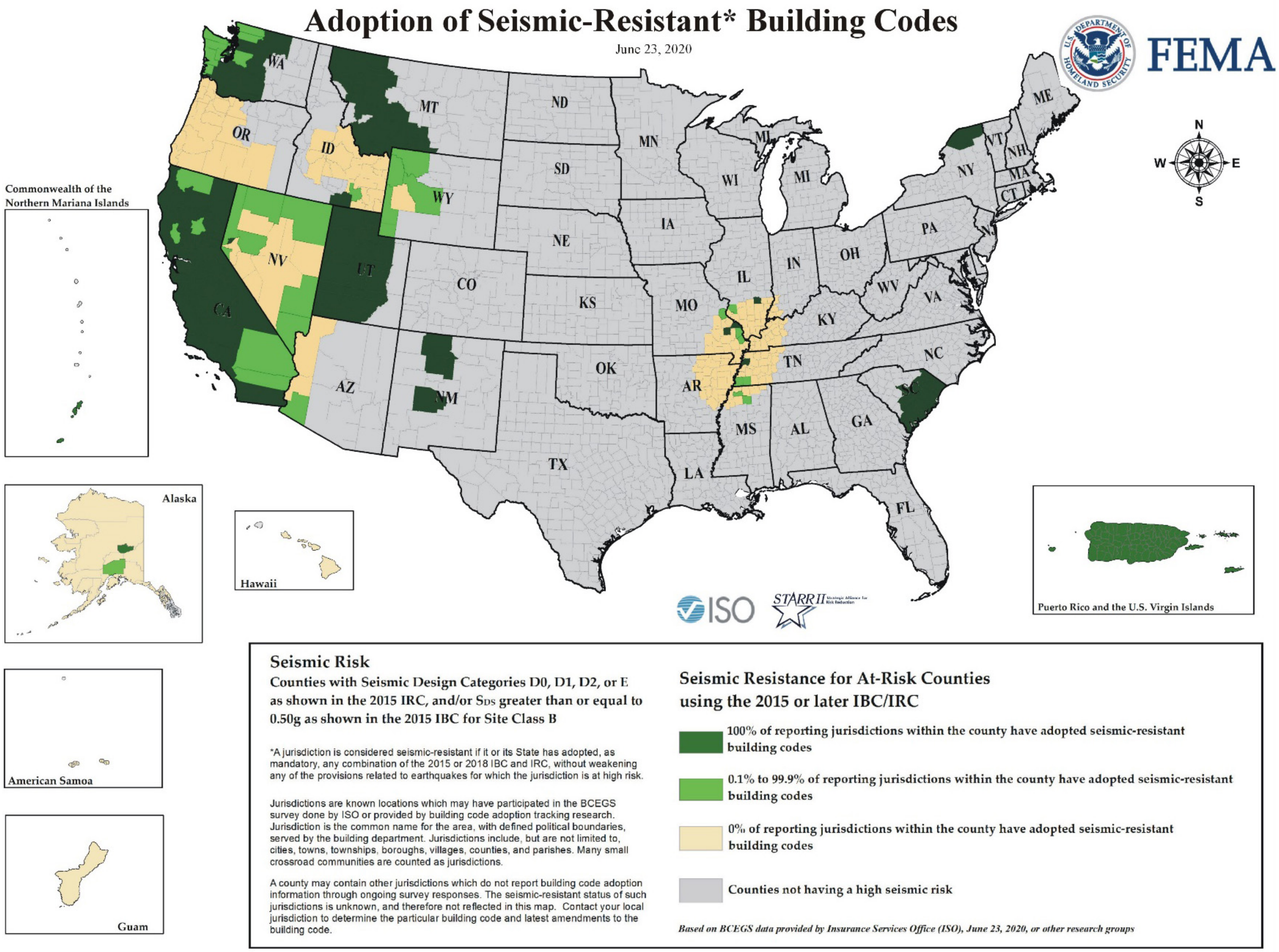
A county may contain other jurisdictions which do not report building code adoption information through ongoing survey responses. The hurricane-resistant status of such jurisdictions is unknown, and therefore not reflected in this map. Contact your local jurisdiction to determine the particular building code and latest amendments to the building code.

Hurricane Resistance for At-Risk Counties using the 2015 or later IBC/IRC

- 🟩 100% of reporting jurisdictions within the county have adopted hurricane-resistant building codes
- 🟩 0.1% to 99.9% of reporting jurisdictions within the county have adopted hurricane-resistant building codes
- 🟨 0% of reporting jurisdictions within the county have adopted hurricane-resistant building codes
- ⬜ Counties not having a high risk for hurricane

Based on BCEGS data provided by Insurance Services Office (ISO), June 23, 2020, or other research groups

Figure B-3: Adoption of hurricane-resistant building codes



Adoption of Seismic-Resistant* Building Codes

June 23, 2020

Seismic Risk

Counties with Seismic Design Categories D0, D1, D2, or E as shown in the 2015 IRC, and/or S_{DS} greater than or equal to 0.50g as shown in the 2015 IBC for Site Class B

*A jurisdiction is considered seismic-resistant if it or its State has adopted, as mandatory, any combination of the 2015 or 2018 IBC and IRC, without weakening any of the provisions related to earthquakes for which the jurisdiction is at high risk.

Jurisdictions are known locations which may have participated in the BCEGS survey done by ISO or provided by building code adoption tracking research. Jurisdiction is the common name for the area, with defined political boundaries, served by the building department. Jurisdictions include, but are not limited to, cities, towns, townships, boroughs, villages, counties, and parishes. Many small crossroad communities are counted as jurisdictions.

A county may contain other jurisdictions which do not report building code adoption information through ongoing survey responses. The seismic-resistant status of such jurisdictions is unknown, and therefore not reflected in this map. Contact your local jurisdiction to determine the particular building code and latest amendments to the building code.

Seismic Resistance for At-Risk Counties using the 2015 or later IBC/IRC

🟩 100% of reporting jurisdictions within the county have adopted seismic-resistant building codes

🟩 0.1% to 99.9% of reporting jurisdictions within the county have adopted seismic-resistant building codes

🟨 0% of reporting jurisdictions within the county have adopted seismic-resistant building codes

⬜ Counties not having a high seismic risk

Based on BCEGS data provided by Insurance Services Office (ISO), June 23, 2020, or other research groups

Figure B-4: Adoption of seismic-resistant building codes

APPENDIX C:
Data Processing Methodology and Quality Control

C.1 Summary of Data Processing

This Appendix provides a description of the data processing procedure for the Building Codes Save (BCS) Study. To process the approximately 147 million raw CoreLogic parcel records, as well as a nationwide Microsoft footprint dataset, two different data processing techniques were performed on the data using ArcGIS and Amazon Web Services (AWS). They produced nearly identical results, and were used for both unique computations and for quality and accuracy checks.

C.1.1 ArcGIS Data Processing Procedure Summary

The ArcGIS data processing methodology allows geospatial development of a finalized dataset where the many intermediate steps are individually able to be inspected and edited. This allows a consistent incremental verification of the assigned methodology processes. It also allows inconsistencies to come to light in the nationwide CoreLogic dataset that would propagate irregular or incorrect results nationwide. The processes used in the ArcGIS Method minimize the effect of those inconsistencies, and render a consistent and useable dataset. Errors discovered in the national dataset during the ArcGIS data processing were then able to be accounted for and corrected in the AWS Data Processing Method.

Inspection and Cleaning. The CoreLogic parcel data required an initial inspection and cleaning of several attributes of data involving either repair, replacement, or error removal in the dataset. This includes recalculating the Federal Information Processing Standards (FIPS) County Codes, Latitude, and Longitude for the parcel centroids. Other data in the dataset are then moved to new columns of a different data type (e.g., text versus numeric), because errors were propagated while trying to read the data in their native columns. Additional data processing includes combining the CoreLogic Year Built and Effective Year Built (taking the Effective Year Built when the Year Built equaled zero). The parcels are then tagged with a Hazus “Unspecific” Occupancy Class value. The CoreLogic Land Use codes are converted to Hazus Occupancy Class values; however, for selected records where available land use information is insufficient to identify a single occupancy class, a generalized, non-specific class is applied as an adaptation (e.g., “RES3-” instead of “RES3A,” “RES3B”).

Data Filtering. Extraneous information is removed by a filtering process. First, vacant, unknown, or blank land uses are filtered out. Next, all parcels with a Year Built before the year 2000, or with zero square feet, are filtered out, and so-on following the 9-step process described in Section 3.2.1.

Stacked Parcels. One issue identified with the CoreLogic parcel dataset is that parcels in a larger building, such as apartments or condominiums, are often spatially “stacked” on top of each other in the Geographic Information System (GIS) dataset. This means that multiple similar parcels of the same polygon shape are all stacked on top of each other, adding up to the entire building’s number of units and total square footage. To make these parcels useful for the study, they were merged from individual unit parcels into whole building parcels. Once the individual unit parcels are merged, parcels with less than 500 square feet were filtered out, mainly to remove erroneous entries and non-building parcels from the database.

Building Footprint Reconciliation. To improve spatial localities of the buildings in the parcel, as well as identify the number of buildings on a parcel, the CoreLogic Parcel dataset is combined with the Microsoft Nationwide Footprint Polygon dataset. The Microsoft Footprint dataset is based on aerial imagery to locate footprints across the nation. This type of data helps us identify how many buildings are on a parcel, where on the parcel they are located, and how many parcels are in large buildings. For instances of industrial, commercial, and high-density housing (multi-family residential housing, Hazus RES3A-F occupancies), where adjacent parcels potentially occupy the same large building footprint, parcels of the same land use are merged into individual buildings, like the stacked parcels procedure described previously.

Once the parcels are merged into individual building parcels, the number of units and buildings is tallied using the CoreLogic data and combined with the Microsoft Footprint data. This information is then used to determine a final Hazus Occupancy. Relevant parcel data are transferred to the Microsoft Footprint centroids and the total parcel square footage is divided among the total footprints, with larger footprints obtaining a proportional percentage of the square footage.

Reconciliation of Parcels without Building Footprints. Unfortunately, not all parcels have Microsoft Footprint information (e.g., newer parcels may have been developed after the available footprint data were captured). Parcels with no footprints were identified by the parcel centroid instead of the individual building centroid. These centroids (either building or parcel) were then used to identify the Census Blocks, Census Tracts, County FIPS, Wind Speeds, and Flood Hazards associated with each record in the processed database. With this updated location information, Building and Content Replacement Values were calculated using the updated (2018) Hazus Replacement Cost Model. Once all information is tagged and calculated, the final dataset is reassembled, and individual state-level datasets are created for the flood, hurricane wind, and seismic teams to proceed with their analyses.

C.1.2 Amazon Web Services Data Processing Procedure Summary

The AWS methodology development allows explicit code programming to efficiently compute large tabular volumes of data. Both replication data and modification of the process allow recreation of the process and updating of the CoreLogic database repeatedly, with little additional preparatory work. Theoretically, this methodology would also be able to replicate the nationwide data processing very quickly, after being checked and validated on the local scale, with irregularities cleaned or reconciled from the national dataset. However, the Hazus input and output also require converting the data out of and then back into geospatial domain.

The AWS methodology programming is based on a progression of three "blocks" of processing taking advantage of data frames while processing. They are stored in non-persistent memory. This means no intermediate files are written to storage except at the breaks between blocks.

Each block represents a milestone or break in the processing to assess data quality and accuracy of the programming and computations.

Block 1. Block 1 combines the Microsoft footprint dataset with the CoreLogic parcel database to provide a footprint location within the parcel polygon boundaries. The footprint data were converted to a GeoJSON file for encoding the CoreLogic geographic data structure and its non-spatial attributes into a non-spatial database. GeoJSON is an open-source file format that converts spatial data into code so it can be used outside of a spatial program such as ArcGIS. The result is a BCS Study nationwide point database representing the building centroid locations, appended with the parcel data from CoreLogic.

Block 2. Block 2 appends the building centroid database with flood hazard, wind speed, census block, and Community Identification (CID) information. This is done by running several spatial joins in parallel with the National Flood Hazard Layer (NFHL), CoreLogic flood hazard layer, wind speed contours, Census block polygons, and the CIDs. During Block 2, the data cleaning and filtering described in the AWS process are performed by command programming.

Block 3. Block 3 combines the data from Block 2 with stacked parcel and building footprint reconciliation final calculations described in the AWS process, also performed by command programming. For efficient programming and processing of the big-data joins, a Python Spark SQL (pyspark.sql) module is used. A Python Spark SQL module is a module for structured data processing that enables quick processing of large amounts of data. This Python Spark SQL module was applied to Apache Spark, an open-source data processing framework capable of processing very large datasets by distributing the tasks across multiple computers to be run in tandem. Besides incorporating the previously obtained values from the spatial joins, Hazus Occupancy and building/content replacement value calculations are performed.

C.1.3 Data Processing Conclusions

Of the parcels with known buildings (approximately 123 million), approximately 30% of the data (33 million) have insufficient information to be modeled. Of the remaining 90 million, 20% fit the criteria for the study (e.g., post-2000 building year, footage greater than 500 square feet). The stacked parcel, building footprint, occupancy, and discrepancy reconciliations result in approximately 10% of additional parcels that can be modeled, and would not have been otherwise; mostly in urban areas. The dataset is then applied to Hazard-specific input formatting, and is able to be inspected incrementally to check accuracy of results and perform sensitivity analysis or validations. The final data results can be seen divided by year built for each of the ten Federal Emergency Management Agency (FEMA) Regions in Figure C-1.

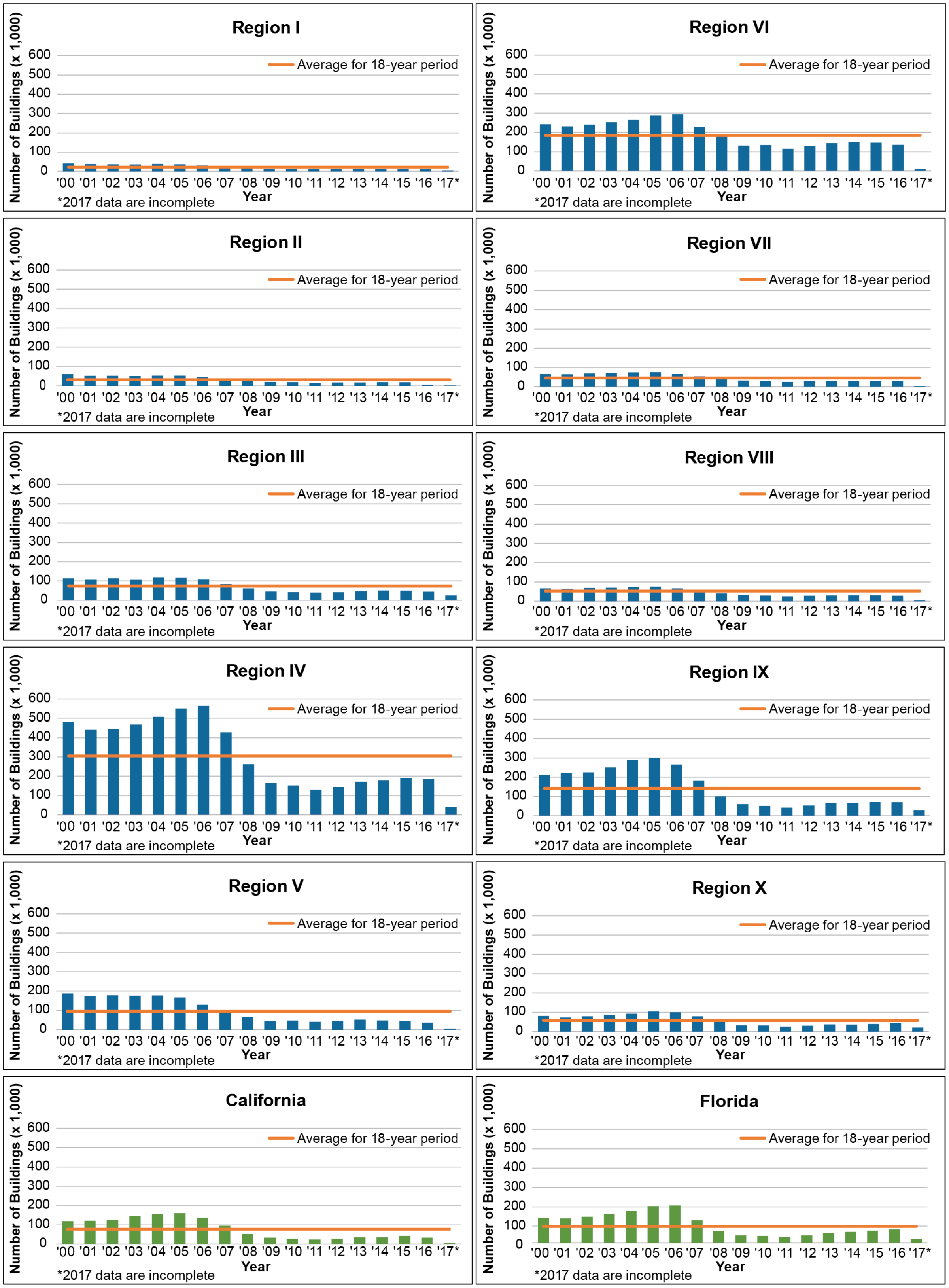


Figure C-1: Number of post-2000 buildings by year for all FEMA Regions, California, and Florida, and the average number of buildings for the 18-year period

C.1.4 Data Quality Control

Process and quality controls were applied to the ArcGIS and AWS databases and their respective programming processes used for the National database. These include random sampling—cross checks of data parameters and statistical methods to compare attributes of each—and allow more efficient computing during the hazard-specific modeling. Both Quality Control (QC) evaluations inspected the data filtering and gap filling process. Following all individual procedures, each portion of the process was reviewed by an independent data analyst to determine the correctness of the programmed functions and accuracy of the processed results.

C.2 In-Depth ArcGIS Data Processing

The goal of the data processing is to convert parcel data into individual building data, and prepare the data for hazard analysis. To do this, there are several obstacles that need to be taken care of in the data, including parcels situated on top of one another (stacked parcels), neighboring parcels in a single building (large buildings), and pinpointing building locations within the parcel boundaries. To prepare the data for the hazards, the data needed to be filtered; several key factors were recalculated; additional data needed to be obtained from outside sources to fill data gaps; and the entire dataset needed to be converted into a usable format. The following is a generalized plan for processing the data that includes the use of external data to supplement the CoreLogic data. Figure C-2 also illustrates the steps described below.

C.2.1 Preprocessing the CoreLogic Data

The CoreLogic data contain a vast amount of information about parcel and building information from across the United States, including building height, construction materials, year built, Assessor values, and location information. However, there were some inconsistencies in the database that were easily reconciled with outside sources, so the CoreLogic data were initially cleaned up to improve data processing. This included combining the CoreLogic "Year Built" and "Effective Year Built" columns. Some communities used these two data fields differently, so when the data were combined, the Effective Year Built was used when the Year Built had no information. The latitudes and longitudes were recalculated using ArcGIS, and the county and state locations were recalculated using Topologically Integrated Geographic Encoding and Referencing (TIGER) county data. The provided Land Use field was then used to identify parcels without buildings on them, such as parks, vacant lots, and unidentifiable parcels.

C.2.2 Level 1 Filter: Empty Parcels

To process the data correctly, the data needed to be filtered in a series of steps, with some calculations between each filtering process. The number of parcels that were filtered out of each step can be seen on a state-by-state basis in Appendix A-1. For the Level 1 Filter, the parcels without buildings identified in the preprocessing step were removed from the database.

C.2.3 Level 2 Filter: Parcels Not Built from 2000 to 2018

The Level 2 Filter identified all of the parcels with buildings built from the years 2000 to 2018 (which were the most recent data in the dataset), and filtered out all of the parcels with either no year-built data, or parcels with buildings built before the year 2000.

C.2.4 Level 3 Filter: Merge Stacked Parcels

One of the more complicated processes involved combining parcels that were situated on top of one another in the CoreLogic dataset. These parcels were identified internally as "stacked parcels." The stacked parcels often represented individual units in a larger building, such as apartments, condos, or offices that were sold piecemeal, but did not represent a whole building. These parcels needed to be merged together to get the information for the entire building. Before that was done, parcels with zero square feet were removed, because these parcels obviously contained faulty data.

Once the zero square feet parcels were removed, the remaining stacked parcels were identified based on identical location and land use, with different land uses being merged separately. The land uses were kept separate to maintain buildings with multiple uses, such as apartment complexes with commercial uses on the lower floors. During the merging of the stacked parcels, the individual data for each parcel were combined to create the data for the entire building, such as adding up the square footage and taking the most common year built listed for all of the stacked parcels.

C.2.5 Level 4 Filter: Square Footage Less than 500 Square Feet

After the stacked parcels were merged into a single parcel, the dataset was then filtered for parcels with less than 500 square feet. This removes anomalous data, as well as buildings that likely are not dwellings, such as sheds and other small buildings.

C.2.6 Level 5 Filter: Merge Large Buildings

In addition to the stacked parcels, there were also parcels that were adjacent to one another, while still in the same building. This is common in locations such as strip malls. For these parcels to be identified, an outside source of data for footprint locations was needed. The Microsoft Bing footprint dataset was determined to be the most widespread and accurate nationwide footprint dataset available, and it was decided this would suit the purposes of this study. The CoreLogic parcel data were then combined with the Microsoft footprint data to identify which footprints belonged with which parcels. This included identifying parcels with multiple footprints, one footprint, no footprints, and footprints that cross parcel boundaries. In the instance of footprints that cross parcel boundaries, neighboring parcels were then merged together, combining the data in the same method as the stacked parcels, to create one parcel per one building.

C.2.7 Level 6 Filter: Parcels to Buildings

The value of the building footprints is that they provide an increased level of locational accuracy, as well as improve our knowledge of how many buildings reside on a parcel. Once the number of buildings was known for each parcel, this information was used in combination with the land use, square footage, and number of units to determine the Hazus Occupancy for each of the parcels. Many of the Hazus Occupancies were a straight conversion from the CoreLogic Land Use, such as commercial and industrial properties; however, the multi-family dwelling buildings such as apartment complexes and condominiums needed a more complicated set of calculations.

After the calculation of the Hazus Occupancy, the parcel data were then transferred to the building footprint centroids on each parcel. For parcels without footprints, the parcel centroid was used as the building location. For parcels with multiple footprints, the parcel square footage was divided up among all of the footprints, and the occupancies and other data copied to each footprint. Following the conversion of parcel data to building data, additional overlapping building centroids were identified and merged together using the same method as previous merges.

C.2.8 Level 7 Filter: Counties with Less than 10 Buildings

The building centroid data were used to identify the census blocks in which each building was located. The 15-digit census block number was then used to determine census tract, county, and state for each building. Counties with less than 10 buildings were identified, and those specific buildings were removed. Those buildings were often a result of counties where there was little to no CoreLogic data available; however, buildings from neighboring counties were close enough to the borders that they became associated with these empty counties. Instead of running the data for an entire county for a couple of incorrectly located buildings, these buildings were removed from the database.

C.2.9 Final Data Calculations

After the census blocks and census tracts were identified for each building, that information was combined with the square footage and previously calculated Hazus occupancy, and was used to calculate the building replacement value and the contents replacement value.

For the hurricane wind hazard analysis, the building data were combined with the wind speed American Society of Civil Engineers (ASCE) maps to determine local wind speeds for each building. Buildings within a 1-mile buffer of the coastline were also identified.

For the flood hazard analysis, the building data were combined with the NFHL to identify buildings in the Special Flood Hazard Areas (SFHA). For areas where there were not current, digitized NFHLs, CoreLogic provided digitized flood hazard layers based on historic paper National Flood Insurance Program (NFIP) panels.

Additional information needed for the seismic analysis was completed by the seismic team; therefore, no additional work was required in the data processing. A visual summary of the data processing procedure is provided in Figure C-2.

C.3 ArcGIS Quality Control

The purpose of the Quality Assurance/ Quality Control (QA/QC) process is to evaluate and ensure adequate quality of the building inventory data developed for use in the BCS Study. The QA/QC approach seeks to identify potential inconsistences between the collected data and reality; to identify potential logical flaws or deviations driving these inconsistencies; and to estimate the impact of such flaws on the project outcomes.

It is assumed that the final building inventory dataset will have imperfections. In many cases, the source data themselves are inconsistently formatted, or simply wrong. The logic used to consolidate the final dataset attempts to resolve some of these issues, but others are beyond the scope of this task. Furthermore, the QA/QC process involved quickly evaluating the data from a wide variety of angles. The broad scope of the BCS Study required that the building inventory be very large. To be able to quickly evaluate this large dataset, the QA/QC process relied on a subset of the final dataset—one out of every hundred records. This sampling should be statistically representative of the greater dataset.

The first component of the QA/QC process was a thorough review of the steps used to develop the dataset. This review involved critical evaluation of potential flaws such as implicit assumptions, inconsistent assumptions, and logical handling of "corner cases" where extreme scenarios based on values in multiple fields or extreme building footprint shapes might trigger unexpected results. Such flaws were carefully considered if they were perceived to affect significant values to be used in later analyses, such as the number of units in a building, the number of buildings in a parcel, the square footage of a building, the number of parcels stacked on a given area, or the land use types. As potential flaws were identified, the impact was determined based on the number of potentially affected locations. Flaws that were identified as significant by the team were corrected. Others were marked as "known issues" and deemed to be insignificant.

The second component of the QA/QC process was a review of the output data themselves. This involved a variety of spot-checking steps, including randomized spot checking, spot checking familiar areas (where the reviewer has first-hand knowledge of the locations), and spot checking urban areas. It also involved evaluation of each of the final fields in the output data table. This field-by-field assessment of the data allowed the reviewer to carefully evaluate outliers in a single variable, and to plot records using multiple fields to identify multivariate outliers. These checking methods allowed for both a targeted check (looking for potential flaws in areas where they seem most likely to occur), as well as a generic check (reviewing data quality at large).

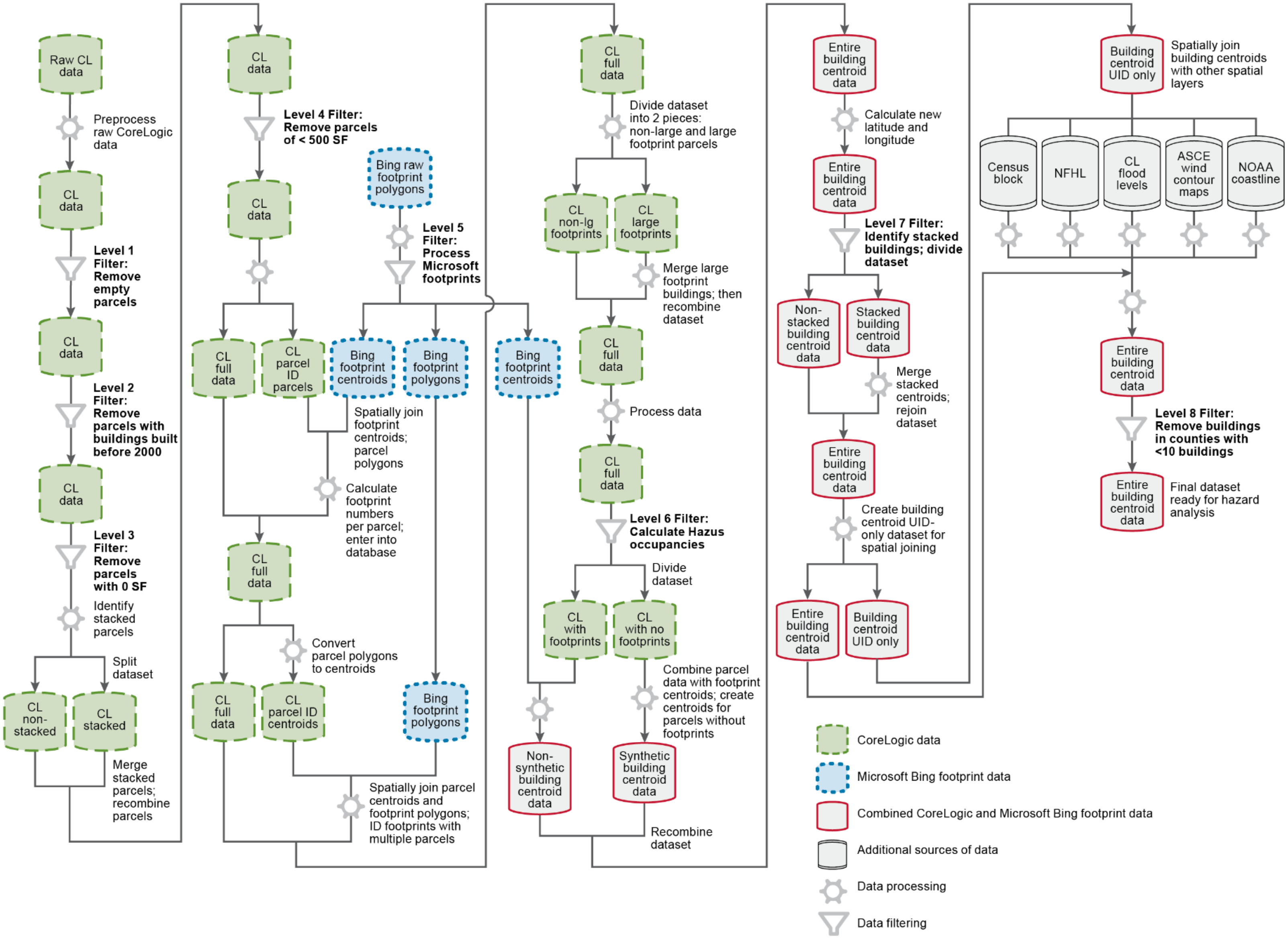


Figure C-2: Diagrammatic flowchart of the ArcGIS data processing procedure

C.4 In-depth Amazon Web Services Data Processing

To determine whether building design mitigates damage during a disaster, resulting in a loss avoidance, the first step is to understand structure locations and building characteristics. The methodology used for the nationwide loss avoidance study was to determine location using both building footprint polygons and parcel polygons.

C.4.1 Block 1: Building Stock Methodology

1. **Bing Building Footprints –** The input file is a GeoJSON file. It contains feature geometry of polygons without any other attributes. GeoJSON is an open-source file format that converts spatial data into code so that it can be used outside of a spatial program such as ArcGIS.
2. **CoreLogic Parcels –** The input file is an Esri ArcGIS shapefile. It contains 89 attribute fields that include a field with polygon geometry.
3. **Processing –** To facilitate table joins, the Bing building footprints are processed to calculate a Globally Unique Identifier (GUID) or Universally Unique Identifier (UUID) for each row in the dataset. UUID version 4 was used to calculate the GUID. The probability of a repeated GUID, or collision, is 1 in 103 trillion. The polygon geometry is then calculated to determine area of the polygon in square feet. The polygons are then converted from a polygon to a point feature using the centroid of the polygon as the point geometry.
4. **Processing –** To facilitate table joins, the CoreLogic parcels are processed to calculate a GUID for each row in the dataset.
5. **Bing Building Footprints –** Bing building footprint point file is written and stored for later processing. GUID and Area fields are appended.
6. **Bing Building Footprints –** Bing building footprint polygon file is written and stored for later processing. GUID and Area fields are appended.
7. **CoreLogic Parcel Polygon –** CoreLogic parcel polygon file is written and stored for later processing. GUID field is appended.
8. **Spatial Join –** The Bing building footprint polygons are spatially joined with the CoreLogic parcel polygons. Building footprints may join with multiple parcel polygons for various reasons, such as spatial misalignment, buildings built across multiple parcels, or other reasons. If a building spatially intersects more than three parcel polygons, then the building polygon is removed from the output dataset (see Figure C-3).

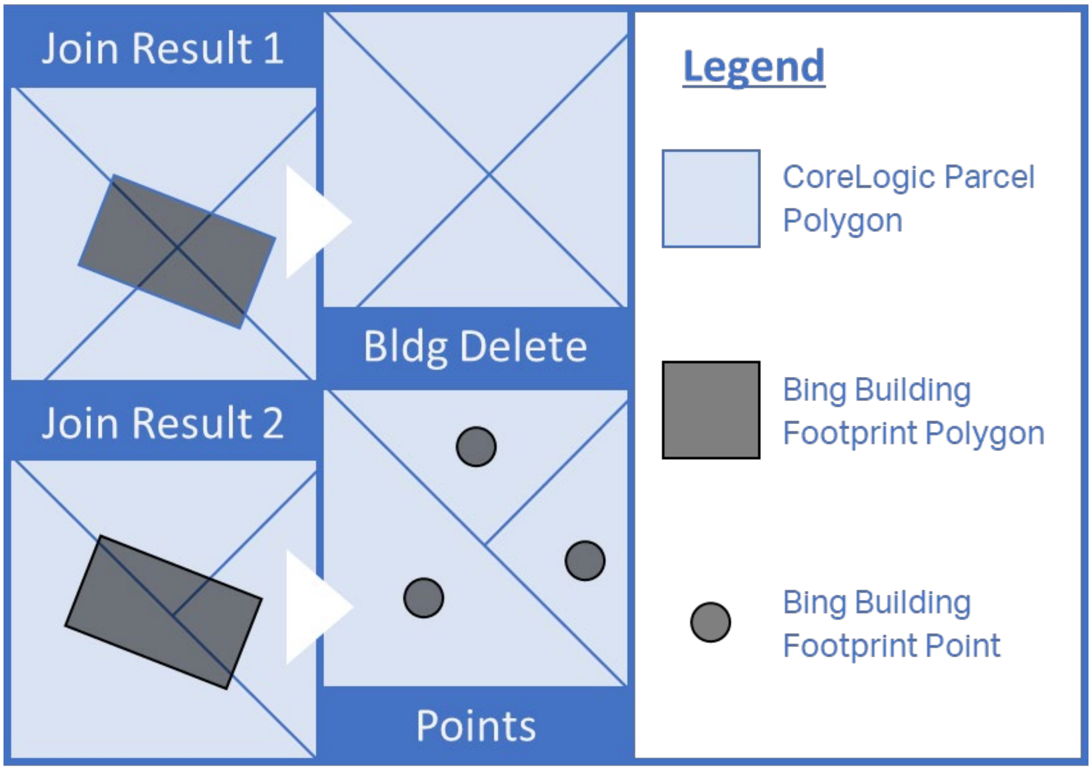


Figure C-3: Examples of join results and processed output

9. **Building Dataset –** The result of the previous spatial join is written and stored as a point file. The file now has a GUID for a building and a parcel. The features also have all attributes from the parcel polygons. The features also have all attributes from the parcel polygons.
10. **Processing –** The parcel data have attributes that indicate a structure is on the parcel, but the building footprints do not have a footprint collocated with the parcel. To fix this relationship, a synthetic building is generated from the CoreLogic data. These data are merged with data from steps 5 Bing Building Footprints, and step 7 CoreLogic Parcel Polygons.
11. **Final Building Dataset –** The result of the previous process is a .csv file written and stored with point latitude and longitude.
12. **Spatial Join –** The previous dataset is spatially joined back with the step 7 CoreLogic Parcel Polygons to assure that populated attributes are correct.
13. **Building Dataset –** The result of the previous spatial join is written and stored as a point file.

A visual summary of Block 1 is given in Figure C-4. Data now proceed to the next phase of processing: Block 2 Data Augmentation.

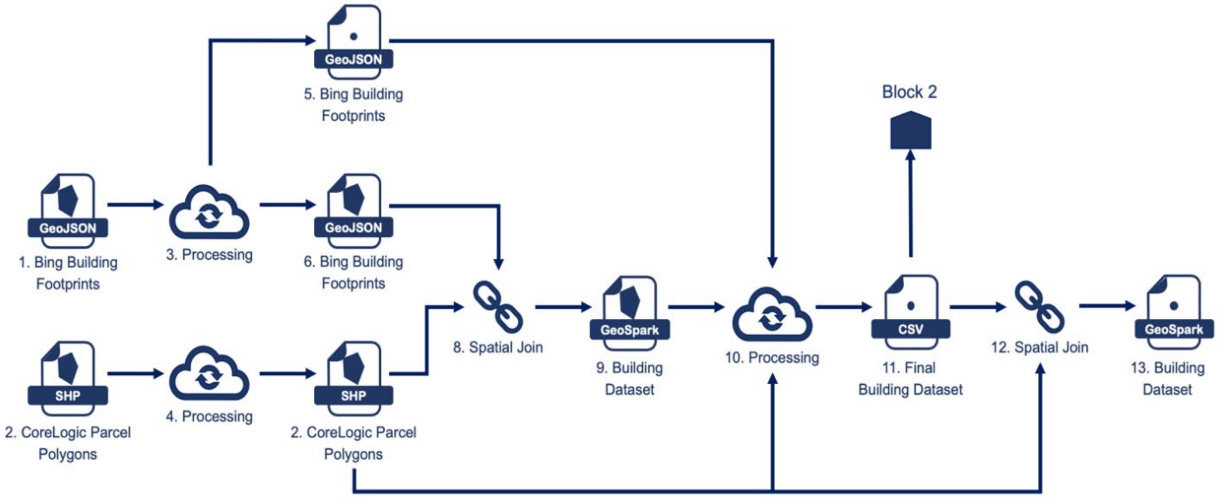


Figure C-4: Workflow process to create a building dataset that is representative of the building stock

C.4.2 Block 2: Data Augmentation

The purpose of Block 2 is to combine the processed data to the external data sources used in the hazard analyses.

1. **ID –** GeoJSON Polygon file with ID numbers.
2. **Spatial Join –** IDs are joined by location with building dataset points, giving the unique building ID row a joined value.
3. ID – Comma-Separated Value output file is created as a Block 3 input.
4. Contour – GeoJSON Polygon file with Wind Contour data.
5. Spatial Join – Contours are joined by location with building dataset points, giving the unique building ID row a joined value.
6. Contour – Comma-Separated Value output file is created as a Block 3 input.
7. Windspeed – GeoJSON Polygon file with Windspeed data.
8. Spatial Join – Windspeeds are joined by location with building dataset points, giving the unique building ID row a joined value.
9. Windspeed – Comma-Separated Value output file is created as a Block 3 input.
10. Community – GeoJSON Polygon file with Community data.
11. Spatial Join – Communities are joined by location with building dataset points, giving the unique building ID row a joined value.

12. Community – Comma-Separated Value output file is created as a Block 3 input.
13. NFHL (FEMA) – GeoJSON Polygon file with NFHL (FEMA) data.
14. Spatial Join – NFHL (FEMA) is joined by location with building dataset points, giving the unique building ID row a joined value.
15. NFHL (FEMA) – Comma-Separated Value output file is created as a Block 3 input.
16. NFHL (CoreLogic) – GeoJSON Polygon file with NFHL (CoreLogic) data.
17. Spatial Join – NFHL (CoreLogic) is joined by location with building dataset points, giving the unique building ID row a joined value.
18. NFHL (CoreLogic) – Comma-Separated Value output file is created as a Block 3 input.
19. Census Blocks – Census Blocks are joined by location with building dataset points, giving the unique building ID row a joined value.
20. Spatial Join – Census blocks are joined by location with building dataset points, giving the unique building ID row a joined value.
21. Census Blocks– Comma-Separated Value output file is created as a Block 3 input.

A visual summary of Block 2 is given in Figure C-5.

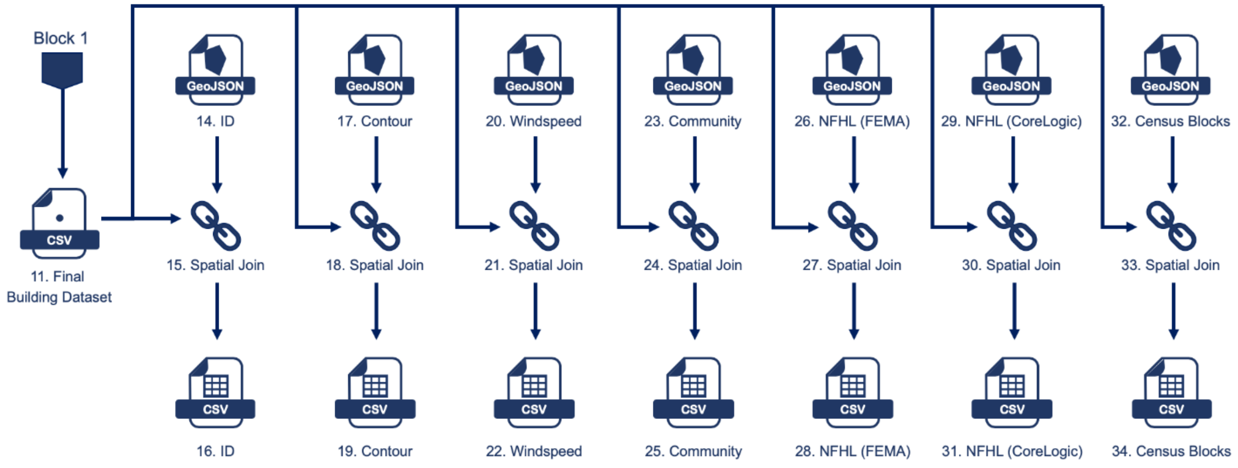


Figure C-5: Workflow process to create files for data augmentation

C.4.3 Block 3: Python Script Processing

Data for the loss avoidance study were blended from several preprocessed data sources and reference look-up tables using Python. Python is a human-readable programming language that contains a comprehensive standard library of tested modules. For the purpose of processing big-data datasets, the pyspark.sql module is used so that Apache Spark can be leveraged.

The process takes advantage of data frames while processing. Data frames are stored in non-persistent memory. No intermediate files are written to storage.

1. **PreProcessed Input –** The output of Block 1 is a preprocessed file that is ready for the Python script. These data are compiled on a statewide scale. This is a tab-separated value (.tsv) file format that contains two fields with nested GeoJSON. The total row count is a combination of all building footprints and all parcels.
2. **countyDFall –** This is the initial data frame loaded with the preprocessed input. Two columns—building area, and building square footage—are numerical, and are loaded as doubles.
3. **Non-Synthetic Building Footprint Area ≥ 500 square feet –** Non-synthetic buildings were previously discussed as those derived from a building footprint. Preprocessing calculated square footage based on the polygon area. This field is filtered to include any row that is greater than or equal to 500 with the synthetic field "manufactured" as false.
4. **countyDFall –** Output data frame.
5. **Extract Parcel Data nested as JavaScript Object Notation (JSON) –** Ten fields from the JSON nested field are extracted as new columns. They are the CoreLogic land use, year built, effective year built, building square footage, FIPS codes, unit numbers, number of buildings, and latitude and longitude values.
6. **countyDFadded –** Output data frame.
7. **GroupBy to aggregate square feet –** Data were grouped by "buildingID," which removes any duplicate buildings generated from joins during preprocessing. The purpose is to understand the total square footage of multi-unit structures. The square footage is summed.
8. dfSQUARE FEET_sum – Output data frame.
9. **Land Use, Building Area, and Year Built –** These were the main filter criteria for buildings for the study. Only some land uses are included with building square footage greater than or equal to 500; and either the year built, or the effective year built, greater than or equal to 1999.
10. **countyDF –** Output data frame.
11. **Calculate Best Year Built –** Because the CoreLogic parcel data do not have a high populated percentage for year built, the effective year built is used if null. The results of the logic statement are stored in an additional column: combined year built.
12. **countyDF –** Output data frame.
13. **GroupBy to aggregate square feet by Land Use –** When building footprints and parcels were joined in Block 1, every building footprint was assigned a row associated

with every parcel. An example is a stacked parcel with 6 parcels that has 2 collocated building footprints, which will result in 12 data rows in step 35 preprocessed input. This is required to correctly characterize the building use equally across the parcel. The parcel may have mixed land use. This is the first process in determining the ratio of land use for the parcel. The data rows are grouped by the unique identifier "buildingID" for the building. Both Non-Synthetic and Synthetic buildings received a unique identifier in Block 1. The additional grouping criteria of land use is also applied. So, if the 6 parcels were 5 residential and 1 commercial, the grouping result would be 2 rows, with the building square footage summed for 5 residential parcels into one row, and a second row for commercial. All other fields apply the first in aggregation method.

14. **groupedDFpre –** Output data frame.
15. **Table Join –** The total square footage of the parcel was calculated in step 41 GroupBy to aggregate square footage prior to the dataset being filtered by step 43 Land Use, Building Area, and Year Built. This total square footage is joined back to the data.
16. **groupedDF –** Output data frame.
17. **GroupBy to aggregate ratio for Synthetic –** The data frame now has the sum of the building square footage from step 47 GroupBy to aggregate square footage by Land Use, and the total square feet from step 41 GroupBy to aggregate square footage. A new column is created so that the sum of building square footage is divided by the total square footage. This should provide the percentage of the building's total square footage by land use.
18. **groupedDF –** Output data frame.
19. **GroupBy to count Land Use –** To determine how many buildings are mixed-use, a "GroupBy" is performed to get a count of buildingIDs by land use.
20. **countsLU –** Output data frame.
21. **GroupBy to count square feet –** To determine the total universal building square footage unique rows by square footage, the countyDF data frame is grouped by "buildingID," land use, and building square footage with a count of rows.
22. **countsUSQ –** Output data frame.
23. **GroupBy to aggregate count of parcels –** To determine the total number of parcels joined to a building, the countDF data frame is grouped by "parcelID" with counts.
24. **buildingCountDF –** Output data frame.
25. **GroupBy for Land Use max count –** To determine the most common land use for a parcel, the countsLU data frame is grouped by "buildingID," and the maximum land use count is written in the "ModeLandUse" column.
26. **resultsLU –** Output data frame.

27. **GroupBy for Area max count –** To determine the maximum building square footage, the countsUSQ data frame is grouped by “buildingID” and land use. The maximum building square footage is written to the “ModeUBLDSQUARE FEET” column.
28. **resultsUSQ –** Output data frame.
29. **Table Join –** This step begins a series of table joins with each join adding to the groupedDF. The groupedDF is joined with the resultLU data frame as a left outer join.
30. **groupedDF –** Output data frame.
31. **Table Join –** The groupedDF is joined with the resultUSQ data frame as a left outer join.
32. **groupedDF –** Output data frame.
33. **Table Join –** The groupedDF is joined with the building count data frame using the default inner join.
34. **countyDF1 –** Output data frame.
35. **Calculate Average square feet –** Average square feet is calculated in the “average square feet” column by using the equation $\frac{\sum Building\ square\ footage}{building\ count}$.
36. **countyDF1 –** Output data frame.
37. **Filter for average square feet –** This is the third filter for a minimum of 500 square feet. The “AvgSquare feet” column is filtered for rows over 500.
38. **countyDF1 –** Output data frame.
39. **GroupBy to remove duplicates –** The countyDF data frame is now grouped by “buildingID” and land use. Duplicates are dropped, leaving unique building IDs by land use with parcel counts.
40. **parcelCountDF –** Output data frame.
41. **Table Join –** The countyDF1 data frame is joined with the parcelCountDF data frame as a left outer join.
42. **countyDF2 –** Output data frame.
43. dfHazusOccupancy – Input data.
44. **Table Join –** The countyDF2 data frame is joined with the dfHazusOccupancy data frame as a left outer join.
45. **countyDF3 –** Output data frame.
46. **Table Join –** The countyDF3 data frame is joined with the FEMANFHL data frame as a left outer join.

47. **countyDF4 –** Output data frame.
48. **Table Join -** The countyDF4 data frame is joined with the dfCommunityData data frame as a left outer join.
49. **countyDF5 –** Output data frame.
50. **Table Join –** The countyDF5 data frame is joined with the dfIDData data frame as a left outer join.
51. **countyDF6 –** Output data frame.
52. **Table Join –** The countyDF6 data frame is joined with the dfContourData data frame as a left outer join.
53. **countyDF7 –** Output data frame.
54. **Table Join –** The countyDF7 data frame is joined with the dfWindSpeedData data frame as a left outer join.
55. **countyDF8 –** Output data frame.
56. **Table Join –** The countyDF8 data frame is joined with the dfCensusData data frame as a left outer join.
57. **countyDF9 –** Output data frame.
58. **HazusOccupancy –** This calculation is still being modified at the time this document is being drafted. The code below is the current logic statement.
59. **countyDF10 –** Output data frame.
60. **Table Join –** The countyDF10 data frame is joined with the dfRES1BV1 data frame as a left outer join.
61. **dfRES1BV1 –** Input data frame.
62. **res1DF –** Output data frame.
63. **Table Join –** The stateDF data frame is joined with the dfCensusRegion data frame as a left outer join.
64. **dfCensusRegion –** Input data frame.
65. **res2DFa –** Output data frame.
66. **Table Join –** The res2DFa data frame is joined with the dfRes2ReplCost data frame as a left outer join.
67. **dfRes2ReplCost –** Input data frame.
68. **res2DFb –** Output data frame.

69. **Table Join** – The res2DFb data frame is joined with the dfhzRepl data frame as a left outer join.
70. **dfhzRepl** – Input data frame.
71. **resOtherDFb** – Output data frame.
72. **Table Join** – The resOtherDFb data frame is joined with the dfLocMeans data frame as a left outer join.
73. **dfLocMeans** – Input data frame.
74. **resOtherDFb** – Output data frame.
75. **Calculate estBRV** – See calculation logic in the table below.
76. **countyDF10** – Output data frame.
77. **Table Join** – The countyDF9 data frame is joined with the dfCOS data frame as a left outer join.
78. **dfCOS** – Input data frame.
79. Calculate estCRV
80. **countyDF9** – Output data frame.
81. **Table Join** – The countyDF9 data frame is joined with the prclareaDF data frame as a left outer join.
82. **countyDF9** – Output data frame.
83. **Filter for RES** – A filter to only have Residential "HazusSpecific" rows.
84. **Filter for COM** – A filter to only have Commercial "HazusSpecific" rows.
85. **Filter for Rest** – A filter to only have any other "HazusSpecific" rows.
86. **countyDF9Res** – Output data frame.
87. **countyDF9Com** – Output data frame.
88. **countyDF9Rest** – Output data frame.
89. **dfBCEGSRes** – Input data frame.
90. **Table Join** – The countyDF9Res data frame is joined with the dfBCEGSRes data frame as a left outer join.
91. **dfBCEGSCom** – Input data frame.
92. **Table Join** – The countyDF9Com data frame is joined with the dfBCEGSCom data frame as a left outer join.
93. **countyDF9Res1** – Output data frame.

94. **Calculate ADP Year –** Residential Adoption (ADP) Year Calculated.
95. **countyDF9Com1 –** Output data frame.
96. **Calculate ADP Year –** Commercial Adoption Year Calculated.
97. **Table Join –** Appends the Residential, Commercial, and Rest Adoption Years rows together.
98. **countyDF9 –** Output data frame.
99. **QC Final Dataset –** A .csv output used for the purpose of running Quality Control checks using additional fields that are not included in the final dataset.
100. **GDB Final Dataset –** The final output of the Python script in a GeoJSON file that is converted to an Esri ArcGIS Geodatabase format.

A visual summary of Block 3 is given in Figure C-6.

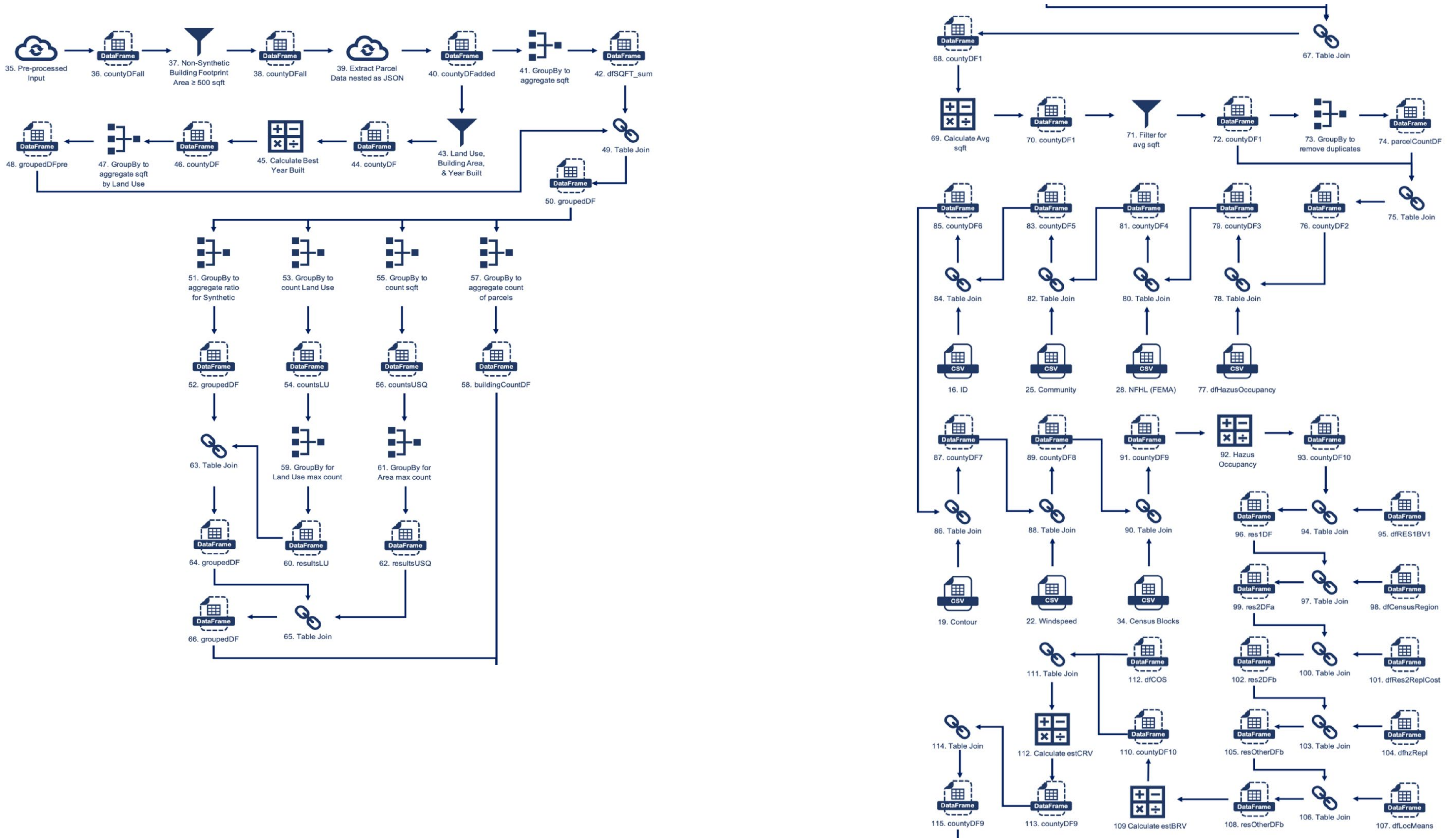


Figure C-6: Workflow process of Python script that processes building stock input and supplemental data to produce final deliverable

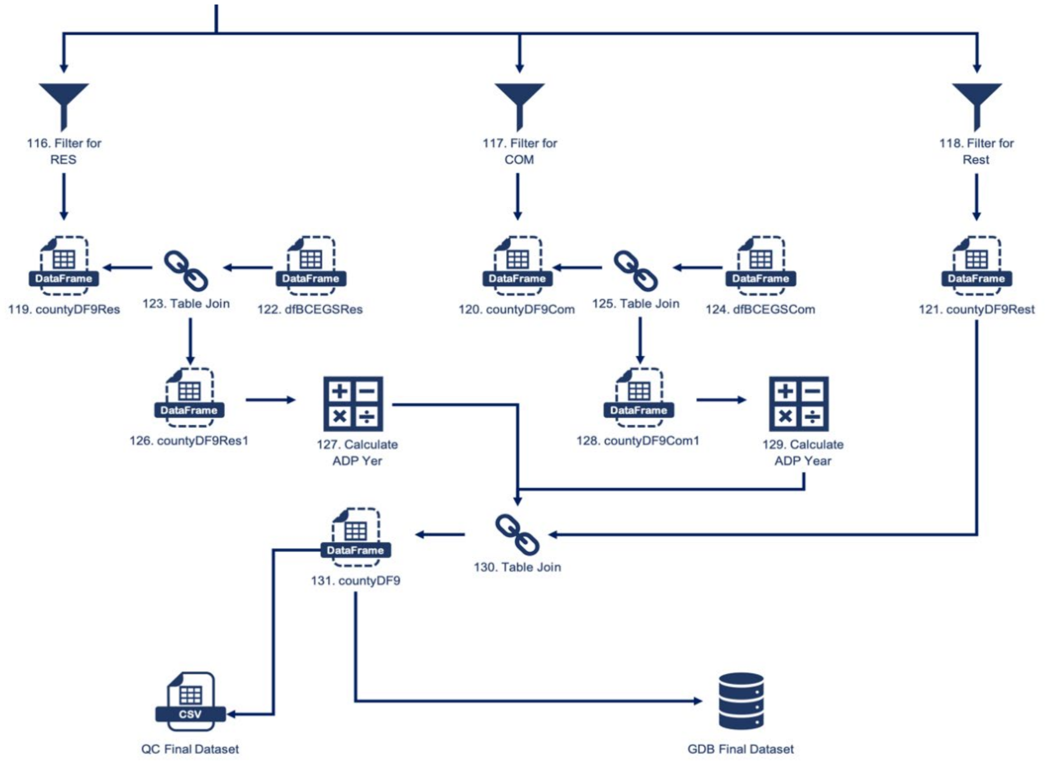


Figure C-6 (cont.): Workflow process of Python script that processes building stock input and supplemental data to produce final deliverable

C.5 Amazon Web Services Data Quality Control

AWS data quality control reviewed data in and between the main blocks of analysis. For Block 1, the main focus was on retention of input data sources in their new AWS formats. Record counts were developed before and after each step in Block 1 to verify that the specific processing of that step did not add or delete unexpected numbers of records. These checks were especially focused on AWS methods related to large buildings and apartments that required combining large number of parcel records into one structure.

For Block 2, the series of spatial joins performed were reviewed to check that the output .csv files contained record counts within the ranges expected for each mapping layer. Because the AWS data were used in a final form for flood analysis only, the reviews were conducted after Block 3 at the state level, which focused primarily on the floodplain structures, and whether all records had properly populated spatial attributes. When a state was found to have an issue with population of one or several of the spatial attributes, Block 2 runtime logs and input and output data were examined to determine the cause of missing spatial attributes. For a majority of the cases, the root cause was found to be source GIS data quality issues, including gaps in geographic coverage, overlapping features and other topological issues, and missing attribution. GIS cleanup was performed on the source GIS data to the extent possible, sometimes including use of supplemental, alternative data sources to replace portions of “corrupted” source data. This was especially true of the FEMA mapping related to the NFIP Political Areas (which contained FEMA NFIP community boundary mapping). Other issues included census block assignments along major water bodies where the structure location point may have been outside of a “clipped” census block boundary. Manual GIS analysis methods using nearest neighbor methods were used to overcome these spatial issues.

For Block 3, the primary focus was population of tabular attributes, and assignment of those fields derived from an initial spatial source. For example, the building replacement values assigned in Block 3 were dependent on a structure having been assigned a Hazus-specific occupancy category, square footage, and spatial assignment of either census block or census tract. If any of these predecessor fields had issues, then the algorithms used to assign building replacement value would have an error. Similar checks were also performed to evaluate big structures and apartments records that were developed by “combining” numerous census parcel records. Because the ArcGIS and AWS approaches combined the data in different ways to create these final set of structures for this set of occupancy types (primarily the RES3 specific occupancies), the comparison of ArcGIS and AWS was also used as way to evaluate completeness of these operations.

C.6 ArcGIS to Amazon Web Services Data Comparison

Comparisons were performed at the state level between the final ArcGIS datasets (Level 7 results) and the final pre-flood AWS datasets (after Block 3). The focus was on the comparison of the within-floodplain subset of both datasets. Overall, the ArcGIS data had 780,048 structures in the floodplain, while the AWS data had 786,473 structures in the floodplain. This difference of around 6,000 structures was less than 1% overall. At the individual state levels, the comparisons were performed on state-specific totals overall; and within the floodplain, with a general guideline of having differences within 10%. In almost all states, the comparisons found counts within 10%, except for a few states with very small within-floodplain counts, where a few hundred in difference might be slightly over 10%. In all states where differences exceeded 10%, the ArcGIS and AWS datasets were compared spatially and at the attribute level to determine causes, and any possibly remedies, to the difference. In some cases, as mentioned in the previous section, the comparison found an underlying Block 2 or Block 3 issue that was addressed through data cleanup activities. In other cases, the main differences were found to be slightly different version of FEMA floodplain boundaries used between the ArcGIS and AWS approaches, or the differences in approaches for the big building structures. This was especially the case when the Microsoft building footprint data did not have a footprint for a multi-parcel structure, and the final dataset remained a stack or series of closely located parcel points. Overall, these cases only represented a small number of states and structures, and did not significantly impact the structure counts in either the ArcGIS or AWS datasets.

APPENDIX D:
Flood Hazard Methodology Details

D.1 Supplemental Information for Flood Code Adoption

This appendix provides additional information to supplement Section 4.1 in the main BCS Study report. Section D.1.1 includes information detailing why freeboard was used as the modeling metric for flood code adoption. This includes detailed discussion on freeboard code adoption history in both the International Residential Code (IRC) and the International Building Code (IBC); the decision not to directly account for IBC structures; and why the decision was made to include manufacturer housing in the flood analysis. The remaining sections detail the multiple-step process used to develop the freeboard adoption database used in this study. Section D.1.2 gives an overview of the state-level data sources used, including those from Association of State Floodplain Managers (ASFPM) and Building Code Effectiveness Grading Schedule (BCEGS). Section D.1.3 provides the detailed methodology used to convert the source Community Rating System (CRS) database data into the annual format needed for the freeboard adoption database. Section D.1.4 provides an overview of the specific local freeboard data sources used in the study. Section D.1.5 provides summary tables on the final freeboard adoption database used for this study.

D.1.1 NFIP and I-Codes

Mandatory minimum requirements for flood-resistant design appeared in community floodplain management regulations before they appeared in building codes. The floodplain requirements were adopted beginning in the late 1960s and early 1970s, following the creation of the National Flood Insurance Program (NFIP), and were comprehensive, incorporating a range of mitigation practices, including elevation of the lowest floor to the base flood elevation (BFE). NFIP requirements have remained largely unchanged since 1971, but some communities have incrementally strengthened their floodplain management regulations above the NFIP minimum requirements, such as adding freeboard above the BFE. Today, more than 21,000 communities at risk of flooding across the country have elected to adopt floodplain management regulations that meet or exceed the NFIP minimum requirements. The NFIP floodplain management requirements also typically cover issues such as administration, floodplain management definitions, floodplain permits, responsibilities of the authority having jurisdiction, floodplain development standards, standards for flood-resistant design and construction, floodway requirements, coastal construction requirements, flood proofing, and variances.

Mandatory flood provisions first appeared in the 2000 International Codes® (I-Codes®). Legacy codes contained little or no mention of flooding. Where there were flood provisions, they were typically optional. When not amended, the flood provisions in the I-Codes are more specific and more comprehensive than the NFIP requirements. Certain administrative provisions and development other than buildings are included in an optional appendix (e.g., IBC, Appendix G). States and communities that adopt the 2012 or later I-Codes with IBC Appendix G and do not make any modifications that weaken the requirements will meet or exceed the NFIP requirements for the purposes of NFIP participation.

NFIP floodplain building requirements and building code flood provisions tend to focus on the same principal issues: elevation of the occupied portions of a building, use of a flood-resistant foundation type, use of flood damage–resistant materials, and other related items and actions intended to minimize flood damage during the base (or design) flood.

The I-Codes and American Society of Civil Engineers (ASCE) 24 contain flood provisions that exceed NFIP requirements for buildings and structures. Although not modeled in this study, these provisions contribute to reduction in physical damage and financial losses, and include:

- Higher freeboard requirements for Flood Design Class 3 and 4 structures
- Required elevation of utility systems and equipment, including freeboard above the BFE
- Prohibition of slab-on-fill and perimeter wall/crawlspace foundations in Coastal A Zones
- Required flood openings in breakaway walls, regardless of flood zone

For a discussion of several differences between the NFIP regulations and the I-Code requirements related to specific terminology and provisions, see Federal Emergency Management Agency/International Code Council (FEMA/ICC) *Reducing Flood Losses Through the International Codes: Coordinating Building Codes and Floodplain Management Regulations*, 5th Edition (FEMA/ICC, 2019). See also *NFIP/2018 I-Codes and ASCE 24 Checklist* (FEMA, 2017c), which compares flood provisions of the 2018 I-Codes to the minimum requirements of the NFIP.

D.1.1.1 Use of IRC with Freeboard Adoption Assumptions

Because more than 80% of structures with freeboard are typically residential (and covered under the provisions of the IRC), this study focused on IRC adoption and the freeboard provisions of each IRC code edition as the primary code savings data component of the model. The 2000, 2003, and 2006 editions of the IRC do not mention freeboard or building above the NFIP BFE.

The 2009 and 2012 IRC editions introduced a limited approach to freeboard. In these editions, freeboard is imposed only in Coastal High Hazard Areas (Zone VE) as a function of orientation of the lowest horizontal structural member of the lowest floor. In those editions, R322.3.2 required the bottom of the lowest horizontal structural member of the lowest floor to be at or above BFE plus 1 foot when the lowest horizontal structural member of the lowest floor was "oriented perpendicular to the direction of wave approach, where perpendicular shall mean greater than 20 degrees from the direction of approach."

This distinction is a function of orientation that originated in ASCE 24-05, *Flood Resistant Design and Construction* (ASCE, 2005), and first appeared in the 2009 IRC. ASCE 24-14, *Flood Resistant Design and Construction* (ASCE, 2014), eliminated the elevation distinction as a function of orientation, which then led to FEMA proposing elimination as part of the proposal to require 1 foot of freeboard in all flood zones. ASCE 24-14 commentary acknowledges that this change was made due to the difficulty in determining the direction of wave approach at many sites, and also because it simplifies design and enforcement. Waves from a storm tracking along a coast will, over the course of the storm, track from multiple directions. CoreLogic attribute data only provided general information on foundation types, and did not have sufficient detail to estimate orientation of the lowest horizontal structural member of the lowest floor relative to the direction of wave approach, which is also difficult to determine. For these reasons, to provide a conservative result, this Building Codes Save (BCS) Study does not assume the default 1 foot of freeboard for structures in Coastal A Zone (CAZ) or Zone V areas constructed under the 2009 and 2012 IRC editions. However, if supplemental local or CRS data indicated freeboard for these structures, they were modeled with the freeboard levels derived from those other sources.

Finally, with the 2015 and 2018 IRC Editions, 1 foot of freeboard was adopted for Zone AE, CAZ, and Zone VE, shown on NFIP mapping. For the communities that adopt these code editions, the assumption is that all structures in the SFHA include 1 foot of freeboard.

D.1.1.2 Freeboard Flood Requirements in the IBC

Since 2000, the IBC has referenced ASCE 24 for flood-resistant design requirements. The 2000 and 2003 IBC reference ASCE 24-98; the 2006, 2009, and 2012 IBC reference ASCE 24-05; and the 2015 and 2018 IBC reference ASCE 24-14. ASCE 24-05 introduces requirements specific to Coastal A Zones. Freeboard in ASCE 24 depends on flood zone and Structure Category/Flood Design Class, which is assigned to each structure based on the nature of occupancy and acceptable level of flood risk. Higher Structure Category/Flood Design Class corresponds with higher elevation requirements. The I-Codes use the term design flood elevation (DFE) to mean the elevation of the design flood, which must equal or exceed the base flood. In communities that adopt the Flood Insurance Rate Map (FIRM) as their regulatory flood map, the DFE is equal to the BFE. However, some community floodplain management ordinances define DFE as the BFE plus freeboard. Table D-1 summarizes ASCE 24 freeboard requirements.

Table D-1: Summary of ASCE 24 Freeboard Requirements

Flood Zone	ASCE 24-98	ASCE 24-05	ASCE 24-14
A Zone (top of lowest floor)	I: DFE II: DFE III: DFE IV: BFE+1 or DFE, whichever is higher	I: DFE II: BFE+1 or DFE, whichever is higher III: BFE+1 or DFE, whichever is higher IV: BFE+2 or DFE, whichever is higher	1: DFE 2: BFE+1 or DFE, whichever is higher 3: BFE+1 or DFE, whichever is higher 4: BFE+2 or DFE, whichever is higher
Coastal A Zone	Same as A Zone	Same as V Zone	Same as V Zone
V Zone (bottom of lowest horizontal structural member parallel to direction of wave approach)	I: DFE II: DFE III: BFE+1 or DFE, whichever is higher IV: BFE+1 or DFE, whichever is higher	I: DFE II: DFE III: BFE+1 or DFE, whichever is higher IV: BFE+1 or DFE, whichever is higher	1: DFE 2: BFE+1 or DFE, whichever is higher 3: BFE+2 or DFE, whichever is higher 4: BFE+2 or DFE, whichever is higher
V Zone (bottom of lowest horizontal structural member perpendicular to direction of wave approach)	I: DFE II: BFE+1 or DFE, whichever is higher III: BFE+2 or DFE, whichever is higher IV: BFE+2 or DFE, whichever is higher	I: DFE II: BFE+1 or DFE, whichever is higher III: BFE+2 or DFE, whichever is higher IV: BFE+2 or DFE, whichever is higher	1: DFE 2: BFE+1 or DFE, whichever is higher 3: BFE+2 or DFE, whichever is higher 4: BFE+2 or DFE, whichever is higher

BFE+1 = base flood elevation plus 1 foot
BFE+2 = base flood elevation plus 2 feet

The assumption was made to focus on residential construction, when needed, when looking for sources for freeboard adoption data. Past studies have shown more than 80% of structures in the Special Flood Hazard Areas (SFHA) are residential structures, almost all falling under the requirements of the IRC. Some sources, such as the FEMA CRS or local freeboard ordinances, usually do not make a distinction for freeboard data between residential and non-residential structures. In contrast, any data sources based only on the IRC or IBC freeboard provisions will have differences in required freeboard for the small percentage of structures that fall under the IBC. In almost all cases, the IBC freeboard will be the same or greater than the IRC freeboard. As the previous table shows, one main difference between IRC and IBC is that the IBC has had freeboard requirement for at least some structure types since 2000. A second main difference between IRC and IBC are for code editions that used ASCE 24-05, and for Flood Design Classes with DFE = BFE + 2 feet, which applies more to Zone V and CAZ construction than Zone A. A very small percentage (less than 5%) of structures in this study were in Zone V. 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 developing IBC-only freeboard adoption that would only apply to a small percentage of structures over a portion of the years for the Study.

Table D-2 gives the breakdown of how Hazus-specific Occupancy Classes are associated with the IRC or IBC and which Flood Design Class.

Table D-2: Hazus-Specific Occupancy Class Associated with IRC or IBC

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

This table will be used to estimate the number of IBC structures that were missed or had their freeboard underestimated, as detailed in Appendix D.4.

D.1.1.3 Freeboard Flood Requirements for Manufactured Housing

The U.S. Department of Housing and Urban Development established minimum National Model Installation Standards in 2007, which are codified in Title 24 Part 3285 of the U.S. Code of Federal Regulations (24 Code of Federal Regulations Part 3285). Manufactured housing structures in flood hazard areas must meet NFIP requirements for buildings and structures. Additionally, FEMA 85, *Manufactured Home Installation in Flood Hazard Areas* (FEMA, 1985), is incorporated by reference. FEMA 85 does not require freeboard.

Starting with the first edition in 2000, the IRC has included the optional Appendix E, “Manufactured Housing Used as Dwellings.” An IRC-adopting state or community can choose to include this additional set of requirements applicable only to “a manufactured home used as a single dwelling unit installed on privately owned (non-rental) lots.” This appendix includes additional requirements related to placing manufactured housing on permanent foundations, including any minimum elevation requirements that may include the freeboard requirements from Chapter 3 of the 2015 and 2018 editions of IRC. Starting with the first edition in 2000, the IBC has included the optional Appendix G, “Flood Resistant Construction” which covers development in flood hazard areas. IBC Appendix G requires new and substantially improved manufactured housing to be elevated to or above the DFE.

For flood modeling, it was assumed that no freeboard is included for manufactured housing relative to other construction in the communities, and construction dates where freeboard is included in residential structures. The primary reasons to not assume freeboard include lack of adoption of Appendix E; different local and state requirements in mobile home parks versus single-family lots; and lack of data on individual structures in these parks.

- In the code review for the BCS Study, very few states were found to have adopted Appendix E, and those that did, like New York State, adopted widespread revisions of the code language. The same lack of information on whether manufactured housing foundations are required to be built with freeboard also applied to the many states where freeboard adoption is driven by state-level freeboard regulations.
- In many states, manufactured housing in a mobile home park has a different set of requirements than those on typical single-family lots. Those structures in a park are often not treated like normal, taxable residential structures, but rather as personal property like a car or boat. Often the tax assessor’s records (which form the basis of the CoreLogic data used for the BCS Study) will have few, if any, manufactured housing structures.
- The date of construction for the entire park tends to be the construction date of the park’s business office structure. Even smaller lots with a typical residential structure and a manufactured housing structure on the same lot may show only one structure in the records; or show two structures, but apply the same construction date to both structures.

Based on the above, the most reasonable assumption was not to model manufactured housing with freeboard as part of this study. However, the methodology did acknowledge that future studies should take a closer look at individual state-level adoption of codes that include freeboard for manufactured housing structures.

D.1.2 State-Level Data

To establish the code adoption dates for each state, code adoption histories were obtained from several sources (BCEGS primarily; but also ASFPM and the CRS Program), described below.

- **BCEGS.** The code adoption histories for IRC and IBC used by the three hazards were derived primarily from BCEGS data. Starting from the state adoption tables shown in the 2015 and 2019 editions of the *National Building Code Assessment Report* (ISO, 2015; ISO, 2019), each hazard analysis used additional detailed BCEGS databases, state code summaries, and other available online resources to determine state-level adoption dates, and which states had mandatory local adoption requirements. Depending on the states and specific counties covered by hazard and how each hazard used the code adoption dates for modeling, the analysis focused on different aspects of the code adoption histories. For example, the flood analysis focused on the IRC and the states with mandatory local adoption when they adopted the 2015 or 2018 codes (with 1-foot freeboard requirements for all flood zones). Because of the proprietary licensure and usage agreement for the detailed BCEGS data used in this study, this BCS Study report was not able to distribute detailed final tables of the code adoption histories, and therefore includes generalized summary tables reflecting freeboard adoption dates.
- **ASFPM**: ASFPM has conducted surveys of states over time related to local and state freeboard adoption. These surveys provided a starting place to review state floodplain regulations to confirm when freeboard was first adopted at the state level.
  - ASFPM surveys from 1992 in *Floodplain Management in the United States: An Assessment Report, Volume 2* (L. R. Johnston Associates, 1992); see Table 11.3.
  - 2003 ASFPM Report Appendix, *Tables of Data, Appendix to Floodplain Management 2003, State and Local Programs* (ASFPM, 2004); see Table A18.
  - ASFPM freeboard list from February 2015 (ASFPM, 2015).
- **CRS:** The primary CRS database used for this study was provided by Molly O'Toole, CRS Program, via email on December 3, 2018). In addition, supplemental data for this study were obtained from the CRS Resources webpage (https://crsresources.org/), which includes state-level information on when a state may have adopted a statewide freeboard.
- **Personal Communication**. Several state officials were contacted by email to obtain both local freeboard data and confirmation of statewide assumptions (see Section D.1.4 for more details).

D.1.3 Community Rating System Data

Another primary source of freeboard information is the NFIP CRS. The CRS is a voluntary program that allows communities to earn flood insurance premium discounts by enforcing mitigation practices and higher floodplain management standards. Participating communities are evaluated across 19 activities. One of the activities reviews regulatory standards, which provides points based on freeboard level as a scoring criteria.

CRS data are reported annually as communities submit documentation to recertify. However, while CRS credits are reported annually, community assessments are performed less regularly; therefore, reported community CRS data values may remain unchanged for several years between assessments.

The BCS project team evaluated historical freeboard CRS credit data reported from 2005 through 2018 to the CRS Program. These data were analyzed and converted (using the process detailed in the following discussion) into feet of freeboard to determine default freeboard values for participating communities over time.

D.1.3.1 Overview of CRS Data Analysis

Assigning Freeboard Levels

CRS source data tags each community with three separate CRS freeboard classifications, when appropriate. The three different classifications are usually related to the area-weighted freeboard value for different types of flood zones (A versus V), or areas with detailed studies versus limited detail studies. Prior to 2013, the scores roughly followed a 100 point per 1 foot of freeboard criterion, with 300 points being the maximum. The 2013 CRS Coordinator’s Manual (FEMA, 2013) changed the awarding of points for freeboard, as shown in Table D-3, with a maximum of 500 points for freeboard.

Table D-3: CRS Freeboard Credit Points (as of 2013)

Freeboard	No Filling Restrictions	Compensatory Storage Required	Fill Prohibited
1 foot	100	110	120
2 feet	225	250	280
3 feet	375	440	500

Source: FEMA (2013)

Because of this change in 2013, scores in the CRS source data based on the 2013 or later CRS Coordinator’s Manuals require a modified approach.

For this BCS Study, two data conversion tables were developed. Table D-4 covers scoring using CRS Coordinator’s Manuals published prior to 2013, and the second table covers scoring as defined in the 2013 and 2017 manuals. Table D-4 gives the pre-2013 CRS data conversion, and Table D-5 gives the 2013 and 2017 CRS data conversion manual scoring.

Table D-4: Pre-2013 CRS Freeboard Data Field Conversion

CRS Freeboard Classification (CRS points)	Freeboard Assigned for Structure
< 37	0
37 – 74	0.5 foot
75 – 149	1 foot
150 – 224	2 feet
225 – 300	3 feet

Source: FEMA (2007a)

Table D-5: 2013 and 2017 CRS Freeboard Data Field Conversion

CRS Freeboard Classification (CRS points)	Freeboard Assigned for Structure
< 37	0
37 – 74	0.5 foot
75 – 164	1 foot
165 – 280	2 feet
281 – 500	3 feet

Source: FEMA (2013)

For this BCS Study, detailed local freeboard adoption data were available for many locations, including both Florida and Texas, for certain time periods. Available freeboard values were compared to the CRS source data values from the same time period, and used to establish ranges of values for different freeboard levels.

The pre-2013 conversions use 0.5-foot freeboard range to best represent communities that had freeboard in a portion of the community, often having 1 foot of freeboard in areas with detailed studies, and no freeboard in areas with historical Zone A (unnumbered) flood boundaries only. For conversion of 2013 and later data, the 0.5-foot range was kept, but all other ranges were extended upward to reflect the higher scores now possible for the same freeboard level. Although some communities have a 1.5-foot freeboard level, there is no clear trend to support a consistent way to establish a range for that freeboard value.

CRS Data Analysis Process

CRS freeboard data provide more than a single data point per community, and therefore require an in-depth data analysis to go from CRS freeboard scores to freeboard levels for a few years to each individual year.

The consolidated CRS source data were imported into an interim MS Access database for analysis and transformation. The data were reformatted to display in a linear or flattened format, field names were adjusted, and additional metadata fields were added. The new table consists of the fields shown in Table D-6. The consolidated dataset rendered freeboard data from 1,572 communities (50 states, the District of Columbia, and Puerto Rico), with assessment years dated from 1997 through 2017.

There were numerous assumptions required to deal with data gaps as missing or incorrect field values for one or several fields.

Table D-6: Working CRS Access Database

Field Name	Description
ID	Record unique identifier
TabMethod	Worksheet tab name referenced method representing the CRS method
TabDate	Worksheet tab name referenced month and year representing the CRS reported year
CID	Community ID
Name	Community Name
State	State Abbreviation
FRB_Value	Freeboard score value
FRB_Type	Freeboard score name (FRB1, FRB2, FRB3, cFRB)
YearAssessed	The allocated year the community was assessed
YearAssessedSource	The source of the Year Assessed value

Freeboard Assignments by Year

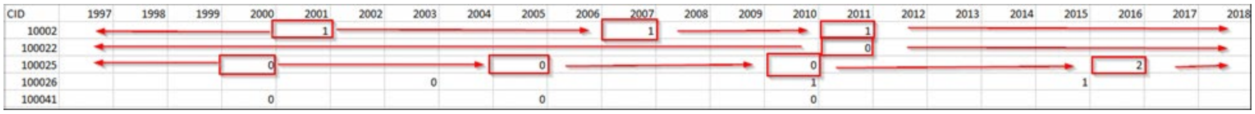
Although the historical CRS data have reported annual values from 2005 to 2018, the Year Assessed values provide a broader timespan for analysis, with values ranging from 1997 to 2017. Overall, the Year Assessed is considered a more accurate reflection of freeboard values regarding time, and is used as the time variable for CRS freeboard analysis.

To determine freeboard values over time, the CRS-designated feet of freeboard and associated Year Assessed values across all records were compiled into a distinct dataset. The result was an output that showed each community's freeboard in feet for each year an assessment occurred.

However, because assessments were not conducted annually, not all years yielded results. To populate the freeboard values between years with an assessment and years without an assessment, the methodology listed below was used to fill the gap.

- Years before the first known value of freeboard: assume the first known freeboard value.
- Years between two known freeboard values: assume the previous known freeboard value.
- Years after last known freeboard value: assume the last known freeboard value.

Figure D-1 illustrates how known freeboard values were partitioned, each marked with a red box and arrows identifying the year assignments



CID	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
10002					1						1				1							
100022															0							
100025				0					0					0						2		
100026							0							1					1			
100041				0					0					0								

Figure D-1: Assignment of freeboard values

Once all communities were populated with freeboard values across all years, the Access database table was exported, rendering the Community Identification (CID), year, and freeboard value in feet. The information was reviewed, and consolidated into the master freeboard table to be used in the model calculations.

CRS Freeboard Data Summary

As of 2018, there were 29,006 defined communities across all 50 states and Washington, DC (FEMA, 2018b). Of these, 6,419 communities were listed in the database as not participating, withdrawn, not an NFIP community, or defunct, with the remaining 22,587 communities identified as possibly having freeboard regulations, where freeboard adoption is possible.

From the analysis of the CRS data, there is a total of 1,571 CRS communities with freeboard data, with an overall average of 1.1 foot of required freeboard over the timespan of this study (2000 to 2018).

D.1.3.2 Detailed CRS Analysis Procedures

An Excel workbook containing historical CRS credit values for participating communities from May 2005 through May 2018 was provided to use for CRS freeboard data extraction by Molly O’Toole, CRS Program, via email, December 2, 2018). Freeboard is part of the CRS scoring criteria for Activity 430 for Higher Regulatory Standards. The workbook consisted of 32 individual worksheets with individual activity scoring data, with each containing a month and year reference in the tab name (e.g., “May13”), apart from one unnamed tab identified as “Sheet9.” Some worksheets, beginning with May14, also contained a CRS Method reference in the tab name (e.g., “May14(2007CM)”). In 2013, the CRS had a major overhaul of scoring criteria, so separate spreadsheets were needed after that year to track communities that still fell under older CRS manuals, and those that used the post-2013 manuals. Each worksheet contained CID, Name, State, Year_430, FRB1, FRB2, FRB3, and cFRB columns; however, beginning with the Oct15(2007CM) tab, several worksheets did not have the Year_430 column. Table D-7 provides a list of worksheet fields used for data extraction.

Table D-7: Worksheet Fields Used for Data Extraction

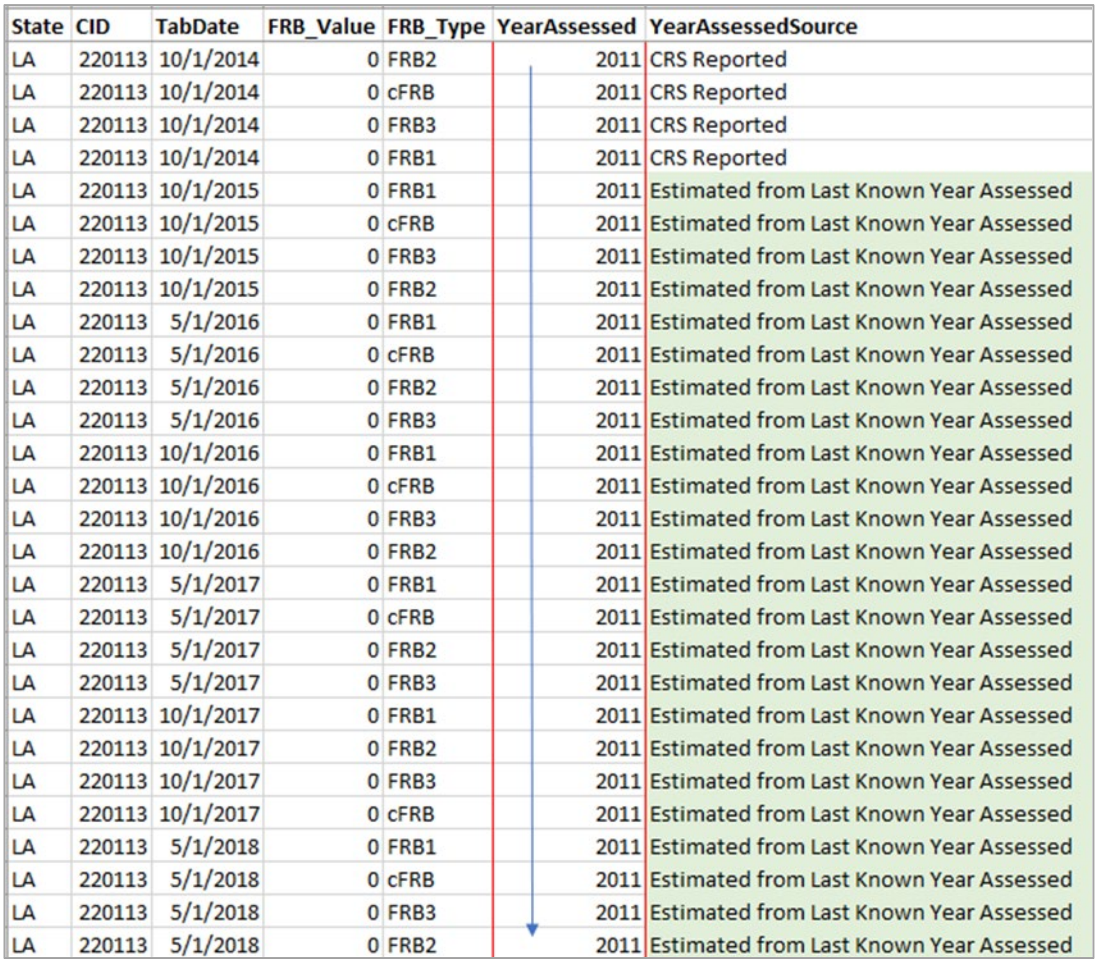
Field Name	Description
CID	Community ID
Name	Community Name
State	State Abbreviation
Year_430	Represents the year CRS assessed items for Activity 430 in the community
FRB1	Freeboard score 1
FRB2	Freeboard score 2
FRB3	Freeboard score 3
cFRB	Freeboard score calculated

Methodology to Populate Missing or "0" Year Assessed Values

The methodology described below was used to populate missing or "0" Year Assessed values.

1. If the missing Year Assessed record had matching freeboard (FRB) values with a record of the same Community that was reported before the missing year record, and had a CRS Reported Year Assessed value, the last known Year Assessed value was populated into the missing record, and identified with a Year Assessed Source of Estimated from Last Known Year Assessed.

In the example (Figure D-2), the last known CRS Reported Year Assessed value was reported as 2011; therefore, all records with missing Year Assessed values and matching FRB values that followed were assigned the last know Year Assessed value of 2011, and noted as Estimated from Last Known Year Assessed.

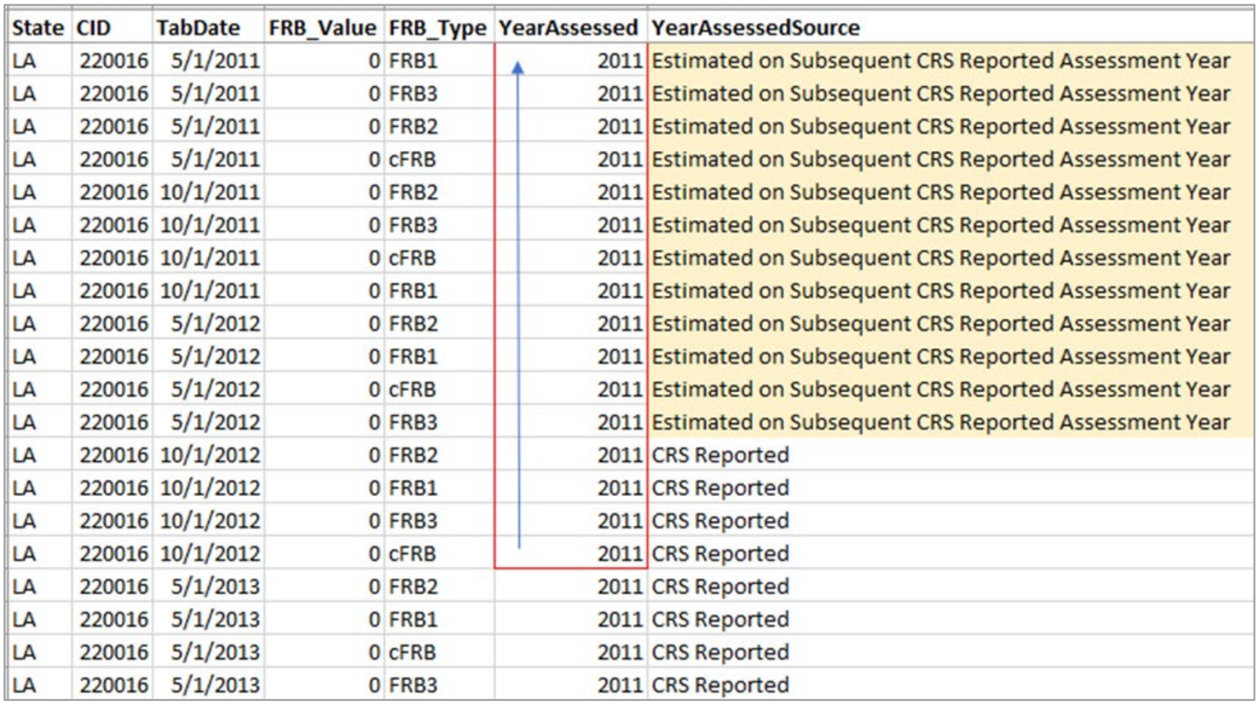


State	CID	TabDate	FRB_Value	FRB_Type	YearAssessed	YearAssessedSource
LA	220113	10/1/2014	0	FRB2	2011	CRS Reported
LA	220113	10/1/2014	0	cFRB	2011	CRS Reported
LA	220113	10/1/2014	0	FRB3	2011	CRS Reported
LA	220113	10/1/2014	0	FRB1	2011	CRS Reported
LA	220113	10/1/2015	0	FRB1	2011	Estimated from Last Known Year Assessed
LA	220113	10/1/2015	0	cFRB	2011	Estimated from Last Known Year Assessed
LA	220113	10/1/2015	0	FRB3	2011	Estimated from Last Known Year Assessed
LA	220113	10/1/2015	0	FRB2	2011	Estimated from Last Known Year Assessed
LA	220113	5/1/2016	0	FRB1	2011	Estimated from Last Known Year Assessed
LA	220113	5/1/2016	0	cFRB	2011	Estimated from Last Known Year Assessed
LA	220113	5/1/2016	0	FRB2	2011	Estimated from Last Known Year Assessed
LA	220113	5/1/2016	0	FRB3	2011	Estimated from Last Known Year Assessed
LA	220113	10/1/2016	0	FRB1	2011	Estimated from Last Known Year Assessed
LA	220113	10/1/2016	0	cFRB	2011	Estimated from Last Known Year Assessed
LA	220113	10/1/2016	0	FRB3	2011	Estimated from Last Known Year Assessed
LA	220113	10/1/2016	0	FRB2	2011	Estimated from Last Known Year Assessed
LA	220113	5/1/2017	0	FRB1	2011	Estimated from Last Known Year Assessed
LA	220113	5/1/2017	0	cFRB	2011	Estimated from Last Known Year Assessed
LA	220113	5/1/2017	0	FRB2	2011	Estimated from Last Known Year Assessed
LA	220113	5/1/2017	0	FRB3	2011	Estimated from Last Known Year Assessed
LA	220113	10/1/2017	0	FRB1	2011	Estimated from Last Known Year Assessed
LA	220113	10/1/2017	0	FRB2	2011	Estimated from Last Known Year Assessed
LA	220113	10/1/2017	0	FRB3	2011	Estimated from Last Known Year Assessed
LA	220113	10/1/2017	0	cFRB	2011	Estimated from Last Known Year Assessed
LA	220113	5/1/2018	0	FRB1	2011	Estimated from Last Known Year Assessed
LA	220113	5/1/2018	0	cFRB	2011	Estimated from Last Known Year Assessed
LA	220113	5/1/2018	0	FRB3	2011	Estimated from Last Known Year Assessed
LA	220113	5/1/2018	0	FRB2	2011	Estimated from Last Known Year Assessed

Figure D-2: Assignment of freeboard for future years

If the missing Year Assessed record had matching FRB values with a record of the same Community reported after the missing year record, and had a CRS Reported Year Assessed value, the subsequent Year Assessed value was populated into the missing record, and identified with a Year Assessed Source of Estimated on Subsequent CRS Reported Assessment Year.

In the example (Figure D-3), the next known CRS Reported Year Assessed value was reported as 2011; therefore, all records with missing Year Assessed values and matching FRB values before that were assigned the subsequent Year Assessed value of 2011, and noted as Estimated on Subsequent CRS Reported Assessment Year.

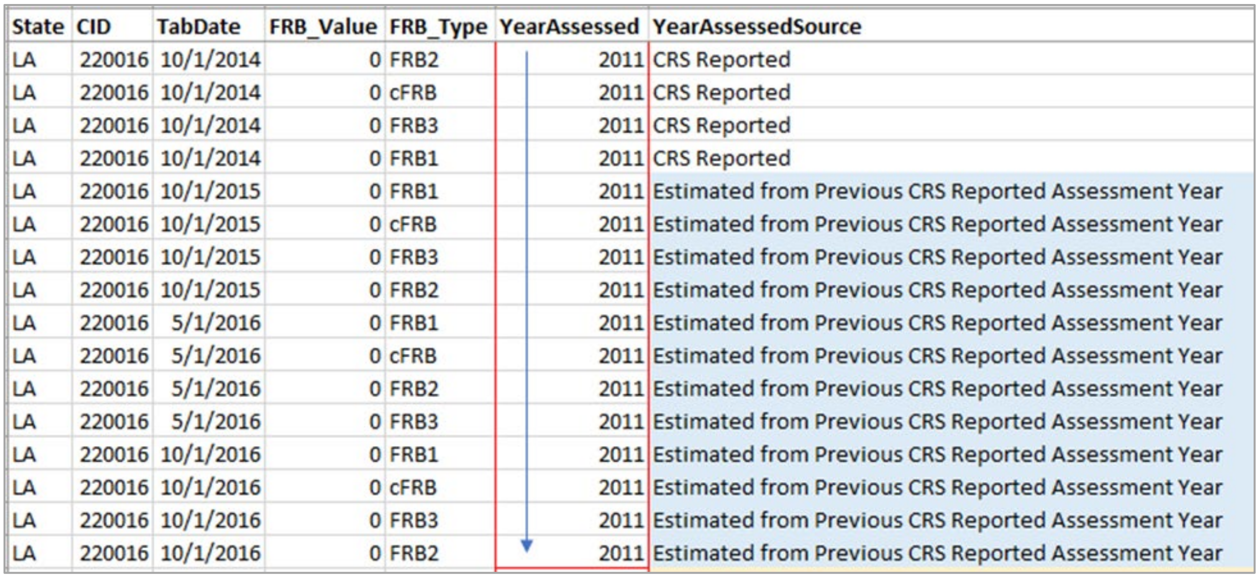


State	CID	TabDate	FRB_Value	FRB_Type	YearAssessed	YearAssessedSource
LA	220016	5/1/2011	0	FRB1	2011	Estimated on Subsequent CRS Reported Assessment Year
LA	220016	5/1/2011	0	FRB3	2011	Estimated on Subsequent CRS Reported Assessment Year
LA	220016	5/1/2011	0	FRB2	2011	Estimated on Subsequent CRS Reported Assessment Year
LA	220016	5/1/2011	0	cFRB	2011	Estimated on Subsequent CRS Reported Assessment Year
LA	220016	10/1/2011	0	FRB2	2011	Estimated on Subsequent CRS Reported Assessment Year
LA	220016	10/1/2011	0	FRB3	2011	Estimated on Subsequent CRS Reported Assessment Year
LA	220016	10/1/2011	0	cFRB	2011	Estimated on Subsequent CRS Reported Assessment Year
LA	220016	10/1/2011	0	FRB1	2011	Estimated on Subsequent CRS Reported Assessment Year
LA	220016	5/1/2012	0	FRB2	2011	Estimated on Subsequent CRS Reported Assessment Year
LA	220016	5/1/2012	0	FRB1	2011	Estimated on Subsequent CRS Reported Assessment Year
LA	220016	5/1/2012	0	cFRB	2011	Estimated on Subsequent CRS Reported Assessment Year
LA	220016	5/1/2012	0	FRB3	2011	Estimated on Subsequent CRS Reported Assessment Year
LA	220016	10/1/2012	0	FRB2	2011	CRS Reported
LA	220016	10/1/2012	0	FRB1	2011	CRS Reported
LA	220016	10/1/2012	0	FRB3	2011	CRS Reported
LA	220016	10/1/2012	0	cFRB	2011	CRS Reported
LA	220016	5/1/2013	0	FRB2	2011	CRS Reported
LA	220016	5/1/2013	0	FRB1	2011	CRS Reported
LA	220016	5/1/2013	0	cFRB	2011	CRS Reported
LA	220016	5/1/2013	0	FRB3	2011	CRS Reported

Figure D-3: Assignment of freeboard for past years

If the missing Year Assessed record had matching FRB values with a record of the same Community that was reported after the missing year record, and had a CRS Reported Year Assessed value, the previous Year Assessed value was populated into the missing record and identified with a Year Assessed Source Estimated from Previous CRS Reported Assessment Year.

In the example (Figure D-4), the previous known CRS Reported Year Assessed value was reported as 2011; therefore, all records with missing Year Assessed values and matching FRB values after were assigned the previous Year Assessed value of 2011, and noted as Estimated from Previous CRS Reported Assessment Year.

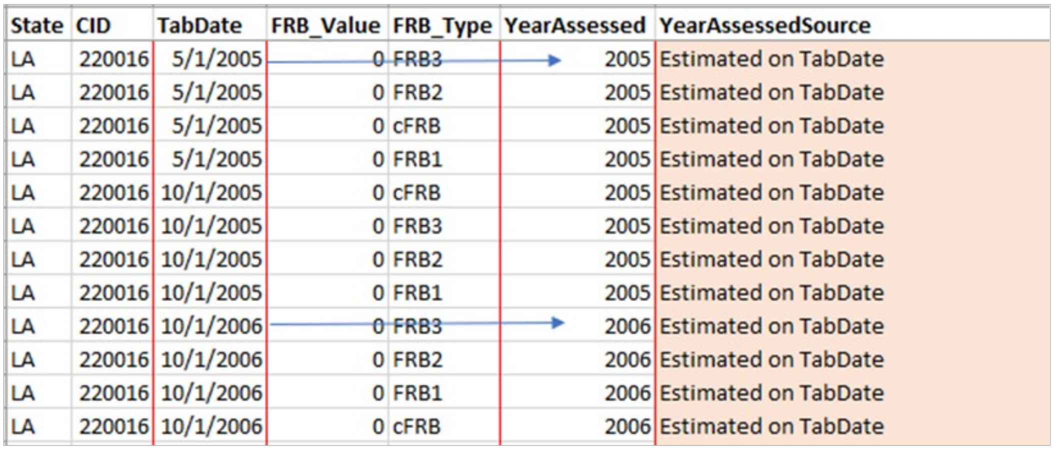


State	CID	TabDate	FRB_Value	FRB_Type	YearAssessed	YearAssessedSource
LA	220016	10/1/2014	0	FRB2	2011	CRS Reported
LA	220016	10/1/2014	0	cFRB	2011	CRS Reported
LA	220016	10/1/2014	0	FRB3	2011	CRS Reported
LA	220016	10/1/2014	0	FRB1	2011	CRS Reported
LA	220016	10/1/2015	0	FRB1	2011	Estimated from Previous CRS Reported Assessment Year
LA	220016	10/1/2015	0	cFRB	2011	Estimated from Previous CRS Reported Assessment Year
LA	220016	10/1/2015	0	FRB3	2011	Estimated from Previous CRS Reported Assessment Year
LA	220016	10/1/2015	0	FRB2	2011	Estimated from Previous CRS Reported Assessment Year
LA	220016	5/1/2016	0	FRB1	2011	Estimated from Previous CRS Reported Assessment Year
LA	220016	5/1/2016	0	cFRB	2011	Estimated from Previous CRS Reported Assessment Year
LA	220016	5/1/2016	0	FRB2	2011	Estimated from Previous CRS Reported Assessment Year
LA	220016	5/1/2016	0	FRB3	2011	Estimated from Previous CRS Reported Assessment Year
LA	220016	10/1/2016	0	FRB1	2011	Estimated from Previous CRS Reported Assessment Year
LA	220016	10/1/2016	0	cFRB	2011	Estimated from Previous CRS Reported Assessment Year
LA	220016	10/1/2016	0	FRB3	2011	Estimated from Previous CRS Reported Assessment Year
LA	220016	10/1/2016	0	FRB2	2011	Estimated from Previous CRS Reported Assessment Year

Figure D-4: Assignment of freeboard with missing year assessed values

If the missing Year Assessed record did not have matching FRB values with a record of the same Community with a CRS Reported Year Assessed value, or had a TabDate prior to the known CRS Reported Year Assessed value, the TabDate year was populated as the Year Assessed value for the missing record, and identified with a Year Assessed Source of Estimated on TabDate.

In the example (Figure D-5), the first known CRS Reported Year Assessed value was reported as 2012; however, the reported TabDates are prior to 2012, and therefore all records prior to 2012 with missing Year Assessed values were assigned as the TabDate year, and noted as Estimated on TabDate.

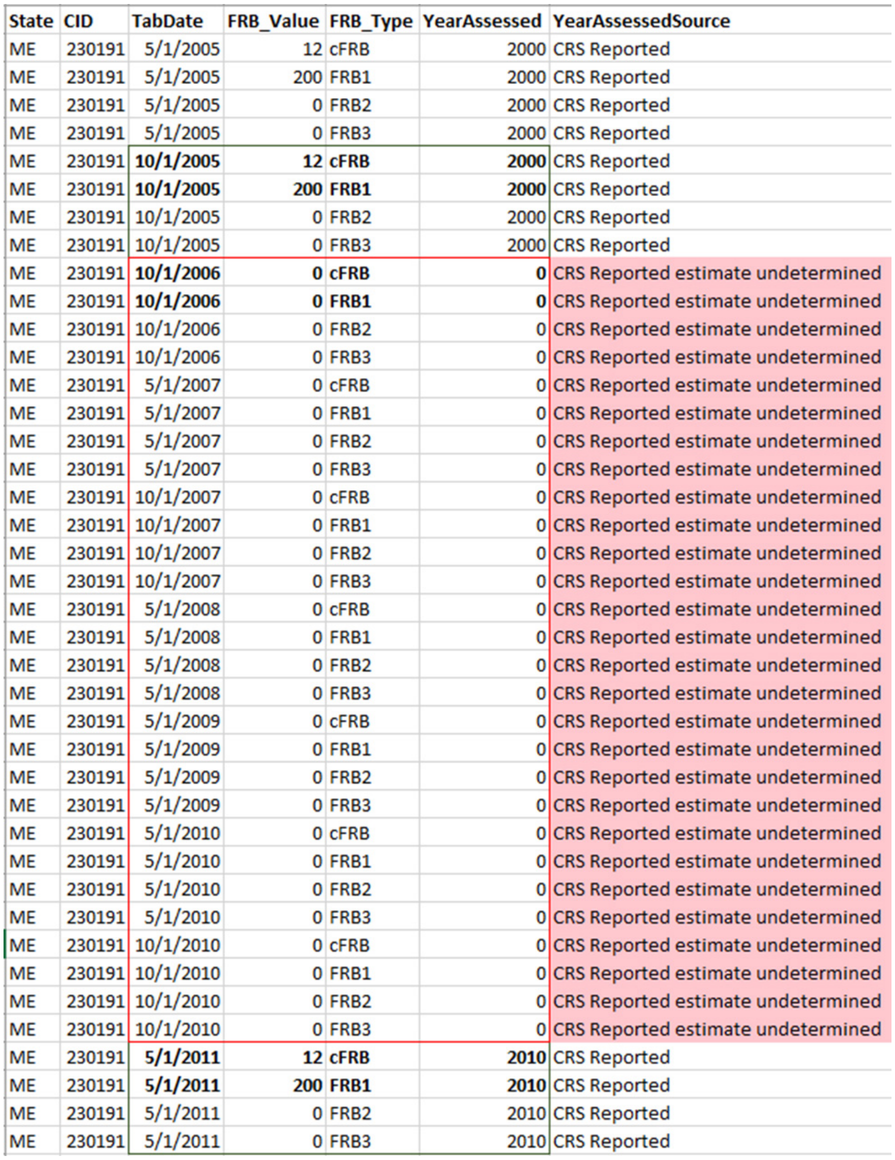


State	CID	TabDate	FRB_Value	FRB_Type	YearAssessed	YearAssessedSource
LA	220016	5/1/2005	0	FRB3	2005	Estimated on TabDate
LA	220016	5/1/2005	0	FRB2	2005	Estimated on TabDate
LA	220016	5/1/2005	0	cFRB	2005	Estimated on TabDate
LA	220016	5/1/2005	0	FRB1	2005	Estimated on TabDate
LA	220016	10/1/2005	0	cFRB	2005	Estimated on TabDate
LA	220016	10/1/2005	0	FRB3	2005	Estimated on TabDate
LA	220016	10/1/2005	0	FRB2	2005	Estimated on TabDate
LA	220016	10/1/2005	0	FRB1	2005	Estimated on TabDate
LA	220016	10/1/2006	0	FRB3	2006	Estimated on TabDate
LA	220016	10/1/2006	0	FRB2	2006	Estimated on TabDate
LA	220016	10/1/2006	0	FRB1	2006	Estimated on TabDate
LA	220016	10/1/2006	0	cFRB	2006	Estimated on TabDate

Figure D-5: Assignment of freeboard with missing records

If the missing Year Assessed record did not have matching FRB values with a record of the same Community with a CRS Reported Year Assessed value, reported either before or after the missing year record, and the TabDate year conflicted with known CRS Reported Year Assessed results, no updates were made to the Year Assessed, and the Assessed Source of CRS Reported estimate was reported as undetermined. Less than 1% of the total CRS population was designated as undetermined.

In the example Figure D-6, the previous known CRS Reported Year Assessed value was reported as 2000; however, the records with missing Year Assessed values did not have matching FRB values. The next known CRS Reported Year Assessed value was reported as 2010; however, the records with missing Year Assessed values did not have matching FRB values. Because both the previous and next known CRS Reported Year Assessed values had matching FRB values, TabDate assignments conflicted with the known values, and therefore the missing Year Assessed values were not populated, and were noted as CRS Reported estimate undetermined.



State	CID	TabDate	FRB_Value	FRB_Type	YearAssessed	YearAssessedSource
ME	230191	5/1/2005	12	cFRB	2000	CRS Reported
ME	230191	5/1/2005	200	FRB1	2000	CRS Reported
ME	230191	5/1/2005	0	FRB2	2000	CRS Reported
ME	230191	5/1/2005	0	FRB3	2000	CRS Reported
ME	230191	**10/1/2005**	**12**	**cFRB**	**2000**	CRS Reported
ME	230191	**10/1/2005**	**200**	**FRB1**	**2000**	CRS Reported
ME	230191	10/1/2005	0	FRB2	2000	CRS Reported
ME	230191	10/1/2005	0	FRB3	2000	CRS Reported
ME	230191	**10/1/2006**	**0**	**cFRB**	**0**	CRS Reported estimate undetermined
ME	230191	**10/1/2006**	**0**	**FRB1**	**0**	CRS Reported estimate undetermined
ME	230191	10/1/2006	0	FRB2	0	CRS Reported estimate undetermined
ME	230191	10/1/2006	0	FRB3	0	CRS Reported estimate undetermined
ME	230191	5/1/2007	0	cFRB	0	CRS Reported estimate undetermined
ME	230191	5/1/2007	0	FRB1	0	CRS Reported estimate undetermined
ME	230191	5/1/2007	0	FRB2	0	CRS Reported estimate undetermined
ME	230191	5/1/2007	0	FRB3	0	CRS Reported estimate undetermined
ME	230191	10/1/2007	0	cFRB	0	CRS Reported estimate undetermined
ME	230191	10/1/2007	0	FRB1	0	CRS Reported estimate undetermined
ME	230191	10/1/2007	0	FRB2	0	CRS Reported estimate undetermined
ME	230191	10/1/2007	0	FRB3	0	CRS Reported estimate undetermined
ME	230191	5/1/2008	0	cFRB	0	CRS Reported estimate undetermined
ME	230191	5/1/2008	0	FRB1	0	CRS Reported estimate undetermined
ME	230191	5/1/2008	0	FRB2	0	CRS Reported estimate undetermined
ME	230191	5/1/2008	0	FRB3	0	CRS Reported estimate undetermined
ME	230191	5/1/2009	0	cFRB	0	CRS Reported estimate undetermined
ME	230191	5/1/2009	0	FRB1	0	CRS Reported estimate undetermined
ME	230191	5/1/2009	0	FRB2	0	CRS Reported estimate undetermined
ME	230191	5/1/2009	0	FRB3	0	CRS Reported estimate undetermined
ME	230191	5/1/2010	0	cFRB	0	CRS Reported estimate undetermined
ME	230191	5/1/2010	0	FRB1	0	CRS Reported estimate undetermined
ME	230191	5/1/2010	0	FRB2	0	CRS Reported estimate undetermined
ME	230191	5/1/2010	0	FRB3	0	CRS Reported estimate undetermined
ME	230191	10/1/2010	0	cFRB	0	CRS Reported estimate undetermined
ME	230191	10/1/2010	0	FRB1	0	CRS Reported estimate undetermined
ME	230191	10/1/2010	0	FRB2	0	CRS Reported estimate undetermined
ME	230191	10/1/2010	0	FRB3	0	CRS Reported estimate undetermined
ME	230191	**5/1/2011**	**12**	**cFRB**	**2010**	CRS Reported
ME	230191	**5/1/2011**	**200**	**FRB1**	**2010**	CRS Reported
ME	230191	5/1/2011	0	FRB2	2010	CRS Reported
ME	230191	5/1/2011	0	FRB3	2010	CRS Reported

Figure D-6: Assignment of freeboard with missing FRB records

Development of Freeboard Matrix

The freeboard matrix provides an assigned freeboard foot value based on a CRS score range and CRS method to reflect changes in the CRS score method. Unknown methods assumed the same matrix values as the 2007 CRS Manual method (FEMA, 2007a). Table D-8 provides the freeboard matrix field descriptions.

Table D-8: Freeboard Matrix Field Descriptions

Field Name	Description
Method	The CRS method associated with the score
CRS_FRB_Min	The minimum CRS freeboard score for range
CRS_FRB_Max	The maximum CRS freeboard score for range
Assigned_FRB_ft	The adjusted freeboard value in feet

Table D-9 presents the matrix with the precise values used to determine feet of freeboard.

Table D-9: Matrix Values Used to Determine Feet of Freeboard

Method	CRS_FRB_Min	CRS_FRB_Max	Assigned_FRB_ft
Unknown	0	36.99	0
Unknown	37	74.99	0.5
Unknown	75	149.99	1
Unknown	150	224.99	2
Unknown	225	300	3
2007 CM	0	36.99	0
2007 CM	37	74.99	0.5
2007 CM	75	149.99	1
2007 CM	150	224.99	2
2007 CM	225	300	3
2013 CM	0	36.99	0
2013 CM	37	74.99	0.5
2013 CM	75	164.99	1
2013 CM	165	280.99	2
2013 CM	281	500	3
2013 and 2017 CM	0	36.99	0
2013 and 2017 CM	37	74.99	0.5
2013 and 2017 CM	75	164.99	1
2013 and 2017 CM	165	280.99	2
2013 and 2017 CM	281	500	3

CM: CRS Manual

Sources: 2007 CM (FEMA, 2007a), 2013 CM (FEMA, 2013), 2017 CM (2017b)

Two example outputs using the above freeboard matrix are:

- If a record has an Unknown tab method with freeboard scores of FRB1(152), FRB2(0), and FRB3(30), the maximum freeboard score of 152 would be compared to the matrix, and the record would be designated as having 2 feet of freeboard per the Assigned_FRB_ft field.

- If a record has a “2013 CM” tab method with freeboard scores of FRB1(152), FRB2(0), and FRB3(30), the maximum freeboard score of 152 would be compared to the matrix, and the record would be designated as having as having 1 foot of freeboard per the Assigned_FRB_ft.

Final Detailed CRS Freeboard Data Summary

Table D-10 summarizes the community counts related to the NFIP, and the CRS related to freeboard. The Total Communities column (total of 29,006 for the 50 states and Washington, DC) reflects all defined communities in 2018 from the FEMA master NFIP CID database. The Non-Freeboard Communities column (total of 6,419) includes the total count of communities listed in the database as not participating, withdrawn, not an NFIP community, or defunct. The Possible Freeboard Communities column (total of 22,587) includes the total count of communities in the CID database listed as NFIP participating (over 99% of communities in this category), suspended, or on probation (also likely to have freeboard regulations) where freeboard adoption is possible. From the analysis of the CRS data, there is a total of 1,571 communities with freeboard data. Finally, the Average CRS Community Freeboard column (overall average 1.1 foot) represents the average freeboard over the time span of this study (2000 to 2018) for the CRS communities. Even with the numerous assumptions in this CRS approach for assigning freeboard values, comparing the statewide freeboard values from Table D-10,this table has very close agreement, even though the CRS lookup tables were built primarily from only Florida and Texas local data.

Table D-10: NFIP Communities and CRS Freeboard Data

State / District of Columbia	Communities (count) Non-Freeboard	Possible Freeboard	Total	CRS Communities (count)	Average CRS Community Freeboard, 2000–2018 (feet)
Alabama	109	435	544	17	1.2
Alaska	101	33	134	7	0.3
Arizona	2	107	109	28	1.1
Arkansas	138	435	573	19	1.1
California	31	528	559	99	0.9
Colorado	66	254	320	48	0.9
Connecticut	26	177	203	14	0.7
Delaware	10	51	61	11	0.4
District of Columbia	1	1	2	0	0.0
Florida	44	467	511	251	0.6
Georgia	152	568	720	54	1.8
Hawaii	1	4	5	2	0.4
Idaho	57	179	236	23	1.3
Illinois	515	900	1,415	67	1.6
Indiana	214	454	668	35	2.0
Iowa	381	692	1,073	11	1.0
Kansas	277	469	746	38	1.3
Kentucky	132	357	489	35	1.1
Louisiana	64	318	382	45	0.4
Maine	52	1,004	1,056	22	0.8
Maryland	18	145	163	15	1.6
Massachusetts	25	342	367	22	0.6
Michigan	673	1,046	1,719	26	1.0
Minnesota	453	611	1,064	9	1.3
Mississippi	59	332	391	32	1.3
Missouri	427	683	1,110	10	1.5
Montana	56	138	194	13	1.8
Nebraska	206	414	620	6	1.0
Nevada	3	35	38	10	1.2
New Hampshire	36	221	257	6	0.3
New Jersey	29	554	583	97	0.8
New Mexico	40	105	145	11	0.3
New York	95	1,511	1,606	43	1.2
North Carolina	93	594	687	89	1.4
North Dakota	198	335	533	12	1.3
Ohio	290	762	1,052	14	0.9
Oklahoma	221	416	637	15	1.2
Oregon	21	261	282	34	1.3
Pennsylvania	175	2,486	2,661	30	1.4

Table D-10: NFIP Communities and CRS Freeboard Data (cont.)

State / District of Columbia	Communities (count)			CRS Communities (count)	Average CRS Community Freeboard, 2000–2018 (feet)
	Non-Freeboard	Possible Freeboard	Total		
Rhode Island	6	40	46	10	0.7
South Carolina	90	236	326	44	1.0
South Dakota	120	230	350	7	0.9
Tennessee	54	400	454	14	1.3
Texas	287	1,259	1,546	64	1.3
Utah	45	222	267	11	0.2
Vermont	71	255	326	7	0.8
Virginia	39	292	331	25	1.1
Washington	45	296	341	37	1.2
West Virginia	17	278	295	10	1.5
Wisconsin	117	569	686	17	2.0
Wyoming	37	86	123	5	0.2

D.1.4 Local Freeboard Data Sources

In addition to the state-level freeboard and CRS data, some states also had available local CRS databases integrated into the final national freeboard database used for the BCS Study. Below are some summaries on these additional data.

- **Florida**: Rebecca Quinn (RCQuinn Consulting, Inc.) worked with Steve Martin from the Florida Division of Emergency Management (FDEM) to provide a comprehensive list of community-level freeboard data (email, July 15, 2019). Rebecca Quinn has worked closely with FDEM and all the Florida NFIP communities since 2012 to replace previously adopted floodplain management regulations with regulations written explicitly to rely on the Florida Building Code (FBC), based on the IRC. FDEM maintains a database of certain higher standards adopted by communities. The most common local amendment is freeboard. This database was provided to help document freeboard levels before and after the recent adoption of the 6th edition of the FBC in 2017 (FBC, 2017), based on IRC 2015 (ICC, 2015b).
- **Texas**: The methodology made use of freeboard survey data from the Texas Floodplain Management Association (TFMA) in 2016 and 2018 (TFMA, 2016; TFMA, 2018).
- **Maryland**: Freeboard information for Maryland was provided by Kevin Wagner with the Maryland Department of the Environment, Water and Science Administration, and included a comprehensive list of local community freeboard adoption above the standard 1-foot statewide criterion in nontidal areas (email, December 11, 2019).
- **Delaware**: The methodology made use of freeboard information provided by the Delaware Department of Natural Resources and Environmental Control, Division of Watershed Stewardship, Drainage and Stormwater Section (DNREC, 2019).
- **Hawaii**: Rebecca Quinn (RCQuinn Consulting, Inc) provided background information on freeboard adoption in two Hawaii counties (email, August 15, 2019).
- **BCEGS**: Local BCEGS data (BCEGS, 2018) provided local adoption information related to IRC 2015 for a small number of communities in states without mandatory statewide IRC adoption. These included Alabama, Arkansas, Missouri, Oklahoma, South Dakota, Tennessee, Texas, West Virginia, and Wyoming.
- **Illinois**: Paul Osman, Chief of Statewide Floodplain Programs, Illinois Office of Water Resources, also provided information concerning statewide freeboard adoption in Illinois used primarily for statewide freeboard adoption assumptions (email, December 10, 2019).

D.1.5 Final Study Freeboard Database

The final freeboard database for this BCS Study was created by bringing together the freeboard data from the statewide data, CRS data, and local data. First, for each community and each year, the greater of the statewide and CRS freeboard levels was calculated. Those communities with only statewide freeboard data were tagged as “State” for the freeboard data sources. Those communities with only CRS freeboard data were tagged as “CRS” for the freeboard data sources. Communities with both statewide and CRS freeboard data were tagged as “Mixed” for freeboard data sources. Finally, where the local freeboard data were available and more stringent than the state and CRS freeboard data, they were tagged as “Local” for freeboard data sources. Because even the best local data, such as Florida’s, did not always cover the full 2000 to 2018 time period, sometimes the local freeboard data were developed manually from a blending of CRS and local data. Also, sometimes the CRS data were more complete than the local data, and the local data were not used for a given community.

Table D-11 gives the total numbers of communities with and without freeboard, along with the average freeboard level of those communities with freeboard.

Table D-12 gives the breakdown of data sources for the communities with freeboard.

Table D-11: Number of Communities with and without Freeboard from State, CRS, and Local Sources

State / Dist. of Columbia	Communities (count)				Average Community Freeboard, 2000–2018 (feet)
	Possible Freeboard	Total without Freeboard	Total with Freeboard	Percent with Freeboard	
Alabama	435	401	34	8%	0.7
Alaska	33	24	9	27%	0.3
Arizona	107	0	107	100%	1.0
Arkansas	435	416	19	4%	1.1
California	528	0	528	100%	0.2
Colorado	254	0	254	100%	0.4
Connecticut	177	163	14	8%	0.7
Delaware	51	9	42	82%	0.4
Dist. of Columbia	1	0	1	100%	1.5
Florida	467	0	467	100%	0.5
Georgia	568	514	54	10%	1.8
Hawaii	4	2	2	50%	0.3
Idaho	179	156	23	13%	1.3
Illinois	900	0	900	100%	1.0
Indiana	454	0	454	100%	2.0
Iowa	692	0	692	100%	1.0
Kansas	469	0	469	100%	1.0
Kentucky	357	323	34	10%	1.1
Louisiana	318	273	45	14%	0.4
Maine	1,004	0	1,004	100%	1.0
Maryland	145	0	145	100%	1.5
Massachusetts	342	0	342	100%	0.1
Michigan	1,046	0	1,046	100%	1.0
Minnesota	611	0	611	100%	1.5
Mississippi	332	300	32	10%	1.3
Missouri	683	653	30	4%	0.6
Montana	138	0	138	100%	2.0
Nebraska	414	0	414	100%	1.0
Nevada	35	25	10	29%	1.2
New Hampshire	221	215	6	3%	0.3
New Jersey	554	0	554	100%	0.7
New Mexico	105	0	105	100%	0.1
New York	1,511	0	1,511	100%	1.4
North Carolina	594	505	89	15%	1.4
North Dakota	335	0	335	100%	1.0
Ohio	762	748	14	2%	0.9
Oklahoma	416	377	39	9%	0.5
Oregon	261	0	261	100%	0.9

Table D-11: Number of Communities with and without Freeboard from State, CRS, and Local Sources (cont.)

State / Dist. of Columbia	Communities (count)				Average Community Freeboard, 2000–2018 (feet)
	Possible Freeboard	Total without Freeboard	Total with Freeboard	Percent with Freeboard	
Pennsylvania	2,486	0	2,486	100%	1.5
Rhode Island	40	0	40	100%	0.5
South Carolina	236	0	236	100%	0.3
South Dakota	230	220	10	4%	0.6
Tennessee	400	384	16	4%	1.1
Texas	1,259	930	329	26%	1.3
Utah	222	0	222	100%	0.1
Vermont	255	248	7	3%	0.8
Virginia	292	267	25	9%	1.1
Washington	296	0	296	100%	0.2
West Virginia	278	259	19	7%	0.8
Wisconsin	569	0	569	100%	2.0
Wyoming	86	77	9	10%	0.2

Table D-12: Freeboard Data Sources

State / Dist. of Columbia	Data Source (count)			
	State Only	CRS Only	Mix of State and CRS	Local
Alabama	0	17	0	17
Alaska	0	7	0	2
Arizona	79	0	28	0
Arkansas	0	19	0	0
California	429	0	99	0
Colorado	206	0	48	0
Connecticut	0	14	0	0
Delaware	0	2	0	40
Dist. of Columbia	1	0	0	0
Florida	1	0	24	442
Georgia	0	54	0	0
Hawaii	0	0	0	2
Idaho	0	23	0	0
Illinois	833	0	67	0
Indiana	419	0	35	0
Iowa	681	0	11	0
Kansas	431	0	38	0
Kentucky	0	34	0	0
Louisiana	0	45	0	0
Maine	982	0	22	0
Maryland	44	0	1	100
Massachusetts	320	0	22	0
Michigan	1,020	0	26	0
Minnesota	602	0	9	0
Mississippi	0	32	0	0
Missouri	0	10	0	20
Montana	125	0	13	0
Nebraska	408	0	6	0
Nevada	0	10	0	0
New Hampshire	0	6	0	0
New Jersey	457	0	97	0
New Mexico	94	0	11	0
New York	1,468	0	43	0
North Carolina	0	89	0	0
North Dakota	323	0	12	0
Ohio	0	14	0	0
Oklahoma	0	15	0	24
Oregon	227	0	34	0
Pennsylvania	2,456	0	30	0

Table D-12: Freeboard Data Sources (cont.)

State / Dist. of Columbia	Data Source (count)			
	State Only	CRS Only	Mix of State and CRS	Local
Rhode Island	30	0	10	0
South Carolina	192	0	44	0
South Dakota	0	7	0	3
Tennessee	0	14	0	2
Texas	0	56	0	273
Utah	211	0	11	0
Vermont	0	7	0	0
Virginia	0	25	0	0
Washington	259	0	37	0
West Virginia	0	10	0	9
Wisconsin	552	0	17	0
Wyoming	0	4	0	5

D.2 Supplemental Information for Flood Hazard Data

This section provides additional information to supplement Section 4.2 in the main BCS Study report. Specifically, it focuses on the details of developing the Probability of Elevation (PELV) Curve database, used to assign flood profiles to each structure as part of the flood analysis. Section D.2.1 provides details on the methodology used to examine the redacted NFIP Policy database for PELV Curve data, and create the multi-geography tables used in the PELV Curve database. Section D.2.2 provides supplemental summary tables on the PELV Curve database, including state-level data.

D.2.1 Flood Profile Modeling: Development of PELV Curve Data

To use PELV Curve data, the initial plan was to obtain a limited detail (state-level only) distribution of PELV Curves from the FEMA Floodplain Management and Insurance Branch. However, in June 2019, FEMA first published NFIP data, including policy records for transactions from the past 10 years. The dataset was distributed through the open government program and is updated on a periodic basis. The dataset is redacted to mask Personally Identifiable Information from public disclosure. The initial dataset published was dated March 31, 2019, and contained 48,261,809 records across 50 states and U.S. territories. Analysis of this dataset indicated that the data could assist in providing floodwater elevations nationwide.

The redacted policy dataset includes policies issued over a 10-year period. This results in a single structure potentially having multiple policies in the data representing duplicate records. Identification of duplicate records is complicated by the redaction of spatial information. The location of the structure covered by the policy is included in the data as latitude and longitude. However, the precision of the coordinate is one decimal place to redact the location. At this broad resolution, the location could be approximately 10 kilometers (6.2 miles) from its original location.

Further review of the redacted policy data revealed flood zone values A1–30 and V1–30 in the policy data. Given the data contained multiple records for each structure and the spatial location was not accurate at a structure level, the data would need to be aggregated.

The dataset was distributed as nine separate files of unsorted and ungrouped data. Using the Konstanz Information Miner (KNIME) open-source data analytic platform to process the data, the first step was to ingest all nine files and sort them by state or territory. The data do not contain a key for a unique structure. To identify a unique structure in the data, a key consisting of several fields was linked together, creating a unique structure-based key for filtering duplicate structure policies. This key consisted of the following data fields: reported city, original construction date, flood zone, and census tract. Grouping by this unique value filtered the initial policy count into unique policies.

Table D-13 provides a summary of record counts by state or territory. For the purposes of this study, the only flood zones of interest were A1–30 and V1–30. The values “*,” “A,” “A-E,” “A0,” “A00,” “A0B,” “A99,” “AE,” “AH,” “AHB,” “ALT,” “AO,” “AOB,” “AR,” “ARE,” “B,” “C,” “D,” “E,” “EMG,” “V,” “V0,” “V99,” “VE,” “X,” and “X0” were filtered out in the flood zone field. The result is a filtered dataset containing a unique representative structure policy where the flood zone has an appropriate value (A1–30 or V1–30) to derive the PELV.

Table D-13: Redacted Policy Data Row Counts

State / District of Columbia	Policy (count)	Unique Policies	PELV Flood Zone
Alabama	462,147	67,528	5,335
Alaska	31,440	4,993	802
American Samoa	1,993	44	—
Arizona	360,728	51,503	1,296
Arkansas	211,377	36,150	1,677
California	2,698,011	354,036	11,011
Colorado	209,387	35,383	1,605
Connecticut	357,191	53,247	8,228
Delaware	220,710	25,054	2,335
Dist. of Columbia	15,984	3,233	47
Florida	14,377,252	1,446,362	152,518
Georgia	989,383	125,762	5,542
Guam	2,641	385	92
Hawaii	199,427	21,660	920
Idaho	71,125	12,145	1,106
Illinois	449,382	78,432	7,546
Indiana	309,233	57,746	8,057
Iowa	165,547	30,819	3,155
Kansas	129,861	23,889	2,387
Kentucky	256,954	41,167	2,939
Louisiana	5,301,560	591,406	93,991
Maine	90,290	15,565	1,820
Maryland	502,951	74,993	16,168
Massachusetts	528,208	84,741	15,983
Michigan	254,847	49,343	6,024
Minnesota	130,568	31,455	2,591
Mississippi	764,907	101,529	11,777
Missouri	266,391	47,944	4,507
Montana	60,969	11,679	1,104
Nebraska	130,359	21,346	2,137
Nevada	143,735	19,976	241
New Hampshire	78,666	13,309	1,011
New Jersey	1,996,820	210,247	58,905
New Mexico	171,426	24,180	477
New York	1,754,028	236,932	25,505
North Carolina	1,380,899	170,202	22,447
North Dakota	146,354	23,016	977
Ohio	409,749	72,308	8,000
Oklahoma	177,722	31,885	1,263
Oregon	331,593	51,562	6,788
Pennsylvania	698,670	117,194	12,247
Puerto Rico	288,422	18,491	2,815

Table D-13: Redacted Policy Data Row Counts (cont.)

State / District of Columbia	Policy (count)	Unique Policies	PELV Flood Zone
Rhode Island	147,895	21,328	4,038
South Carolina	1,701,474	171,910	37,878
South Dakota	56,807	11,046	426
Tennessee	328,900	55,006	1,725
Texas	6,806,523	739,583	40,293
Utah	39,738	8,515	127
Vermont	43,829	7,428	1,231
Virgin Islands	15,068	1,137	112
Virginia	1,115,610	132,557	15,761
Washington	474,593	64,945	11,796
West Virginia	213,142	37,866	4,499
Wisconsin	163,059	33,452	4,070
Wyoming	26,264	4,485	153
Total	**48,261,809**	**5,778,099**	**635,485**

The redacted policy dataset contains fields for three geographic boundary areas. These fields are State/Territory, County, and Census Tract. The State/Territory is the only field completely populated to represent the entire nation. County fields may be populated in the dataset, but not represent all counties in a state. Census Tract fields contained missing or improperly formatted data.

For each geographic area, a KNIME-based analysis process was used to read all state-level PELV filtered and redacted policy data and process it. A1–A30 and V1–V30 were filtered so only A or V flood zone values were processed together. The flood zone was sorted in ascending order from 1 to 30. Once filtered and sorted, a cumulative percentage was calculated for the row.

D.2.2 Flood Profile Modeling: Final PELV Curve Data used for Study

For each geographic unit (census tract, county, state) where the analysis was able to assemble a set of PELV Curve counts, the methodology goal was to have the ability to both estimate the best estimation PELV Curve value, and include PELV Curve values to corresponded to the range of curves found for that geographic unit. Table D-14 give the values for Zone A floodplains, and Table D-15 gives values for Zone V floodplain. The best estimation value corresponds to the center or median value of each set of values, or the 50th percentile. Splitting the set into quartiles gives the 25th and 75th percentiles. Finally, it was decided to use the 10th and 90th percentiles as measures of the extremes of each set. For example, the 10th percentile PELV Curve for Zone A for all of Florida is A3; for Brevard County, Florida it is A8; for Citrus County, Florida it is A2, and for Census Tract 12015020103 in Brevard County, it is A10. The output of the KNIME analysis was six files. The first file is a nationwide dataset with the calculated 10th, 25th, 50th, 75th, and 90th percentiles for A1–A30 flood zone values calculated at the state level. The second file is calculated nationwide at each county level present in the data. The third file is the output at the census block level. The last three files are similar for the V1–V30 flood zone values.

Table D-14: PELV Curves for Zone A

State / District of Columbia	Cumulative Percentage				
	10%	25%	50%	75%	90%
Alabama	A3	A6	A8	A10	A13
Alaska	A1	A2	A3	A5	A10
Arizona	A2	A3	A5	A8	A12
Arkansas	A1	A2	A3	A5	A12
California	A1	A2	A5	A8	A15
Colorado	A1	A3	A5	A7	A9
Connecticut	A4	A5	A6	A8	A9
Delaware	A3	A4	A6	A7	A7
Dist. of Columbia	A3	A4	A10	A12	A12
Florida	A3	A6	A9	A11	A13
Georgia	A2	A5	A10	A15	A16
Guam	A1	A2	A4	A6	A7
Hawaii	A3	A4	A4	A4	A5
Idaho	A2	A3	A4	A8	A12
Illinois	A2	A4	A7	A10	A14
Indiana	A1	A2	A4	A6	A10
Iowa	A4	A5	A7	A9	A11
Kansas	A2	A3	A6	A12	A15
Kentucky	A3	A6	A13	A19	A21
Louisiana	A1	A2	A3	A7	A10
Maine	A1	A2	A2	A5	A9
Maryland	A3	A5	A7	A8	A10
Massachusetts	A2	A3	A8	A11	A13
Michigan	A2	A2	A3	A4	A9
Minnesota	A2	A4	A8	A10	A14
Mississippi	A3	A4	A9	A9	A11
Missouri	A2	A3	A6	A10	A17
Montana	A1	A2	A5	A8	A8
Nebraska	A3	A5	A7	A10	A15
Nevada	A2	A2	A2	A9	A13
New Hampshire	A2	A2	A5	A7	A10
New Jersey	A4	A5	A7	A8	A8
New Mexico	A2	A2	A4	A5	A6
New York	A3	A4	A5	A8	A10
North Carolina	A4	A5	A6	A9	A11
North Dakota	A4	A4	A8	A14	A19
Ohio	A2	A3	A5	A9	A16
Oklahoma	A2	A2	A4	A7	A10
Oregon	A2	A3	A6	A9	A16
Pennsylvania	A3	A5	A10	A14	A18

Table D-14: PELV Curves for Zone A (cont.)

State / District of Columbia	Cumulative Percentage				
	10%	25%	50%	75%	90%
Puerto Rico	A4	A5	A7	A9	A16
Rhode Island	A7	A9	A10	A12	A13
South Carolina	A5	A7	A8	A10	A14
South Dakota	A4	A6	A8	A10	A14
Tennessee	A2	A3	A5	A8	A12
Texas	A2	A6	A11	A13	A16
Utah	A1	A1	A3	A5	A6
Vermont	A2	A4	A6	A8	A10
Virgin Islands	A5	A5	A8	A8	A8
Virginia	A4	A4	A5	A7	A9
Washington	A2	A2	A5	A7	A11
West Virginia	A5	A7	A16	A17	A22
Wisconsin	A2	A3	A4	A6	A8
Wyoming	A1	A2	A3	A4	A5

Table D-15: PELV Curves for Zone V

State / District of Columbia	Cumulative Percentage				
	10%	25%	50%	75%	90%
Alabama	V9	V9	V9	V12	V14
Alaska	V4	V4	V5	V6	V6
California	V3	V4	V5	V6	V8
Connecticut	V5	V6	V7	V9	V10
Delaware	V3	V5	V7	V7	V7
Florida	V9	V13	V15	V17	V20
Georgia	V9	V9	V16	V20	V22
Guam	V6	V7	V8	V8	V8
Hawaii	V12	V14	V22	V23	V24
Louisiana	V15	V15	V16	V19	V21
Maine	V2	V2	V2	V2	V2
Maryland	V6	V7	V7	V7	V11
Massachusetts	V2	V2	V8	V14	V17
Mississippi	V12	V13	V13	V14	V14
New Hampshire	V2	V2	V2	V2	V3
New Jersey	V6	V6	V10	V11	V11
New York	V7	V8	V10	V11	V11
North Carolina	V10	V11	V12	V15	V17
Oregon	V7	V9	V12	V14	V16
Puerto Rico	V7	V9	V11	V12	V12
Rhode Island	V9	V11	V13	V16	V18
South Carolina	V5	V7	V9	V12	V20
Texas	V13	V14	V19	V20	V20
Virgin Islands	V5	V5	V5	V5	V5
Virginia	V6	V7	V13	V13	V13
Washington	V1	V1	V3	V11	V14

D.3 Supplemental Information for Flood Modeling Methodology

This section provides additional information to supplement Section 4.3 in the main BCS Study report. Section D.3.1 provides additional background information on data required to select a flood Depth-Damage Function (DDF). Section D.3.2 provides detailed background information on the development of all the new flood DDFs that were used in the study DDF database. This includes commentary and figures for the range of different residential DDFs originally developed to support coastal Probabilistic Flood Risk Analysis (PFRA) efforts, and then adopted for this study. Additional information was provided on the specific non-residential DDFs created exclusively for this BCS Study, and all the associated contents DDFs that also were not included in the original coastal PFRA work.

D.3.1 Supplemental Information for Flood Modeling Methodology

D.3.1.1 Supplemental Flood Data

Modeling the impact of freeboard on the flood resistance of a structure requires data with enough detail to determine building and contents replacement values, and the selection of an appropriate flood DDF. Flood loss avoidance modeling uses the DDFs to represent with- and without- code scenarios. For example, when a higher standard such as the inclusion of a freeboard requirement is evaluated, the flood loss calculations must be conducted twice—once to determine results before the adoption of freeboard, and a second time to determine results after freeboard adoption. The first calculation would represent a community meeting the NFIP minimum elevation standards, and the calculation would serve as the pre-I-Code baseline for all freeboard scenarios examined. This approach allows losses avoided to be calculated for a return period, such as the 1-percent-annual-chance or base flood event.

Calculating losses for individual structures requires an approach based on the Hazus User-Defined Facilities (UDFs) analysis for flooding. Table D-16 shows the data fields required by Hazus to conduct a flood UDF analysis. To derive structure and contents replacement values, data on the structure square footage and structure replacement value per area (dollars/square foot) from a national costing guide are required. The matter of which DDF is appropriate to select is based on Hazus occupancy type, number of stories, and foundation type (specifically with or without basement). The lowest floor elevation, along with the flood depth obtained from the scenario's flood depth mapping, typically depicted as a raster or grid, is used to determine the "in-structure" flood elevation (flood height above or below the lowest floor).

Table D-16: Critical Data Needed for a Hazus UDF Flood Loss Avoidance Analysis

Hazus Data Field	Description of Data Field
OCCUPANCY	Hazus-specific occupancy type
COST	Structure replacement cost
NUMSTORIES	Number of stories
BLDGTYPE	Hazus building type
LATITUDE	Latitude of structure
LONGITUDE	Longitude of structure
CONTENTCOST	Structure contents replacement cost
FOUNDATIONTYPE	Hazus foundation type
FIRSTFLOORHT	First floor height above grade
BLDGDAMAGEFNID	Structure DDF ID
CONTDAMAGEFNID	Contents DDF ID

Based on the data development work detailed earlier in this report, all structures have been assigned location coordinates, Hazus-specific occupancy type, and structure and contents replacement costs. The CoreLogic source data provided fields related to number of stories, Hazus building type, and Hazus foundation type. The lowest floor height will be assumed related to with- and without-code (for example, freeboard). This leaves the last two data fields from Table D-16 related to structure DDF and contents DDF to be selected.

One additional consideration before discussing how DDF can be selected is related to how flood losses avoided are being calculated. The BCS Study flood analysis will replicate the Hazus UDF calculations outside the Hazus software—in this case, in cloud-based database environment—due to size of the data. Although the most appropriate pair of DDFs (structure and contents) will need to be identified for each structure, the way this pair is selected can be customized to best suit the available data, and to address anticipated data gaps.

D.3.1.2 Number of Stories

The available library of flood DDFs has distinct DDFs based on number of stories for primarily residential structures, especially Hazus-specific occupancy RES1 for single-family residences. The CoreLogic field STORY_NBR includes a numeric value for number of stories for a structure. Data from this field will be used to select DDFs for structures where number of stories is required. This field was usually found to be populated, especially for specific occupancies like RES1, where values are useful for DDF selection.

D.3.1.3 Foundation Type

Like number of stories, many RES1 DDFs also make distinctions between structures with and without basements, and Zone V structures on elevated foundations (such as piers). The foundation type can be determined by reviewing a combination of CoreLogic fields related to basements and foundation types. Specific CoreLogic fields that can be used to determine foundation type include FOUNDATION and BSMT_FNSH (basement finish). These fields tend to not be well populated in the source CoreLogic data. As detailed in the DDF section below, assumptions will be made concerning foundation types when the available data are lacking, and how best to use the data when populated.

D.3.2 Supplemental Information for Flood Depth-Damage Functions

Many studies with the Hazus flood model use the default DDFs available in the Hazus databases. However, for this study ongoing efforts at FEMA related to PFRA provided an opportunity to update the DDFs. Under tasks for Coastal PFRA model development, new sets of structure DDFs were developed that primarily focused on residential structures. Members of the flood analysis staff for this study were also members of the Coastal PFRA DDF Team. In addition to developing new residential curves, the flood analysis was also able to develop a set of non-residential DDFs exclusively for LAS. In addition, the analysis developed contents DDFs for both the new residential and non-residential DDF types. The following sections provide highlights of the process initially used to develop the residential DDFs for the Coastal PFRA effort, and the development of the non-residential DDFs and companion content DDFs.

D.3.2.1 Residential DDF Development

The focus of the Coastal PFRA DDF task was to develop DDFs for single-family residential coastal buildings. These would provide a consistent way to model damages through a progression of increasing damage conditions: from freshwater inundation to saltwater inundation, to moderate waves, to high waves. This approach differs from previous approaches for which many expert panels previously convened to examine a specific flood condition. The initial assessment focused on a review of existing DDFs developed by the U.S. Army Corps of Engineers (USACE) and FEMA, as well as international DDFs where applicable. The USACE and FEMA DDFs were typically developed by a series of expert panels, and summarized in study reports for several projects. Some of the DDFs date as far back as the late 1980s, and included coastal DDFs for the FEMA Benefit-Cost Analysis (BCA) Tool from 2011 and USACE sources from 2015.

The available study reports were reviewed to better understand the approaches of the expert panels, and any assumptions and limitations used as part of their examinations. The DDFs were then adjusted to the same reference point—the finished floor elevation (FFE) at the top of the lowest floor. It should be noted again for this BCS Study report, the abbreviation FFE is being used to represent finished floor elevation, not the more general term first floor elevation, which in this report is referred to as the lowest floor elevation (LFE). From the code standards for riverine structures, the design flood elevation (DFE) is applied to the FFE, which usually is considered to also be the LFE, which typically is measured by surveyors on the top of the lowest floor. For Zone V coastal structures, the DFE is applied to the bottom of the lowest horizontal structural member of the lowest floor. In those cases, the DFE is not at the FFE, but there might be confusion whether the term LFE might represent the "measured survey point" of the lowest floor rather than the FFE.

This confusion made the FFE adjustment to the new DDFs necessary, because some of the coastal DDFs used the lowest horizontal structural member of the lowest floor as a reference point, and some used FFE. Additional adjustments were made to fill in each DDF if there were missing intermediate data points using straight line interpolation. The final adjustment was to shorten the start and end points to the DDFs so that each DDF began and ended at the same elevation points referenced to the FFE. The adjusted DDFs were then grouped into one-story and two-story houses, and initially sorted by the flood conditions of riverine, saltwater, and Zone V areas.

Contrary to the historical application of DDFs (which were selected to represent the flood conditions experienced by the building based on the delineated 100-year flood zone), the Coastal PFRA DDF Team was developing a DDF library based on the flood conditions experienced by the building over a range of flood and wave conditions. This means the same coastal single-family house could use an inundation DDF, a moderate-wave DDF, or a high-wave DDF, depending on the flood conditions being modeled. This was thought to more accurately model building damages and allow the evaluation of DDFs regardless of the depth of flooding in relation to the building FFE. This approach should more accurately reflect risk for the same type of building over a variety of flood conditions. For example, buildings in areas where wave heights could be constrained by fetch (moderate waves) would not reflect as much risk as those in areas where maximum wave heights can occur.

The final assortment of DDFs should represent riverine (freshwater inundation), saltwater inundation (no waves), moderate wave conditions (defined as 1.0- to 2.9-foot wave heights), and high velocity wave action (3.0-foot and higher waves). For each of these flood conditions, it was assumed more damages would accumulate given similar time frames of flooding.

For BCS Study flood modeling, only the riverine DDFs will be used for all Zone A areas, and the high-velocity wave action DDFs for all Zone V areas. The currently available flood data do not have enough detail to be able to assign structures to the two intermediate DDFs curves for saltwater inundation (no waves) or moderate wave conditions. However, the remaining commentary on new DDF curve development addresses all four conditions.

During the evaluation, damage to one-story single-family houses was first assessed for freshwater flood conditions, and this DDF was used as a baseline for comparison against the other coastal DDFs. Post-disaster building assessment knowledge was leveraged against the compared DDFs to aid in selection of the appropriate DDF for the flood conditions. Once the freshwater inundation DDF was selected, the saltwater inundation DDF was estimated based on a limited number of saltwater DDFs in the literature, and based on the knowledge that damage to structural elements would be higher than during freshwater flooding, due to potential saltwater corrosion. Next, the Zone V (high-velocity wave action) condition was evaluated as the most severe type of damage that a one-story single-family house would experience in a coastal flood event. Finally, the Coastal A Zone or Zone A with moderate wave condition (moderate waves) was evaluated. Overall, the general approach in DDF estimation ensures that damage would either increase or remain the same as coastal flood events become more severe (there would be no reduction in damage as flood conditions dictate a switch from one DDF to a more severe DDF).

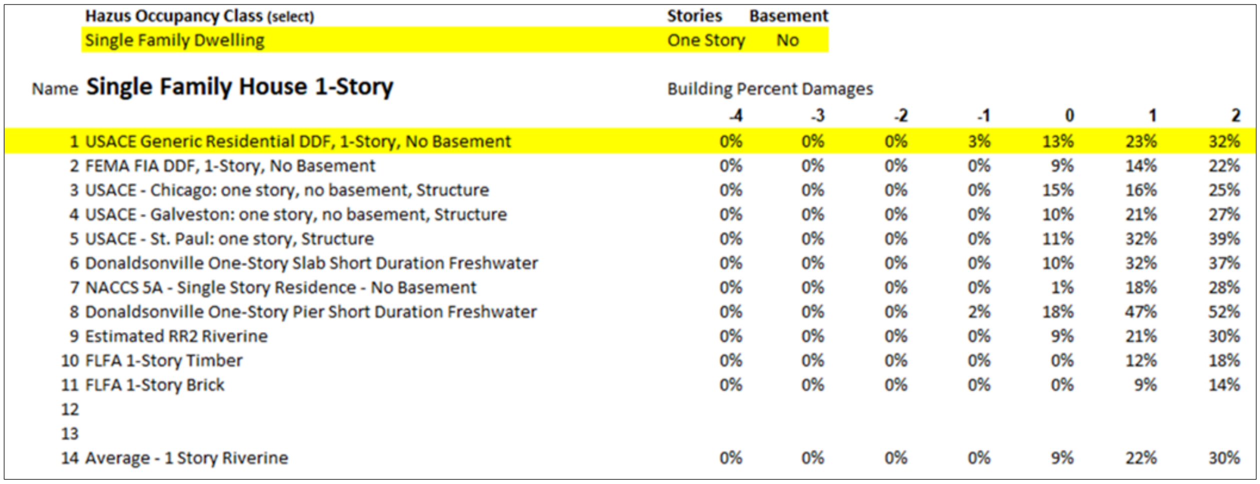
A similar approach was used to evaluate two-story single-family houses. The DDFs for the two-story houses were compared with the one-story houses to determine if the damages were accumulating at a reasonable rate across the various flood conditions.

Once the new coastal DDFs were first estimated, some adjustment (smoothing) of damage percentages was carried out to remove abrupt changes along the DDFs. It was decided that dramatic changes along DDFs were not suitable for the development of Average Annual Losses (AALs), because they could result in abrupt changes in calculated damages based on slightly different flood elevations. In most cases, the adjustments resulted in changes only between 1 and 5% of individual damage percentages, and preserved the overall shapes of the DDFs.

Initial Development of One-Story Single-Family Coastal DDFs

Approximately 11 DDFs were compared for developing the one-story single-family freshwater condition, as shown in Figure D-7. This included a mix of DDFs from USACE, FEMA, and Australia. The DDFs were graphed as shown in Figure D-8, using the X-axis to represent depth of flooding in feet (with a 0-foot depth at the FFE), and the Y-axis representing the percent damage of the building. Based on these curves, an average DDF was developed to provide a comparison. Each individual DDF was then removed from the average DDF one at a time to determine how much influence the DDFs had on the overall average. The individual DDFs were also evaluated to compare when each DDF reached 50% damage, because this is the threshold for Substantial Damage determinations, and for typical structure repair versus replacement. Although this percentage has no impact on overall calculated damage, it provides a useful threshold, based on historical experience with respect to the elevation above the FFE where 50% damage occurs. Figure D-8 shows a circle around the 50% damage value along the Y-axis to facilitate comparison of flood depths where each DDF crosses the line. The DDF for the Riverine PFRA analysis was provided for comparison with the new coastal DDF library.

After evaluating the type of damage that would occur with freshwater flooding and estimating the relative value of various building components that would be damaged per foot of flooding, it was determined the average DDF for the riverine one-story single-family house provided the best representation of damage.



Hazus Occupancy Class (select)	Stories	Basement
Single Family Dwelling	One Story	No

Name **Single Family House 1-Story**

Building Percent Damages

		-4	-3	-2	-1	0	1	2
1	USACE Generic Residential DDF, 1-Story, No Basement	0%	0%	0%	3%	13%	23%	32%
2	FEMA FIA DDF, 1-Story, No Basement	0%	0%	0%	0%	9%	14%	22%
3	USACE - Chicago: one story, no basement, Structure	0%	0%	0%	0%	15%	16%	25%
4	USACE - Galveston: one story, no basement, Structure	0%	0%	0%	0%	10%	21%	27%
5	USACE - St. Paul: one story, Structure	0%	0%	0%	0%	11%	32%	39%
6	Donaldsonville One-Story Slab Short Duration Freshwater	0%	0%	0%	0%	10%	32%	37%
7	NACCS 5A - Single Story Residence - No Basement	0%	0%	0%	0%	1%	18%	28%
8	Donaldsonville One-Story Pier Short Duration Freshwater	0%	0%	0%	2%	18%	47%	52%
9	Estimated RR2 Riverine	0%	0%	0%	0%	9%	21%	30%
10	FLFA 1-Story Timber	0%	0%	0%	0%	0%	12%	18%
11	FLFA 1-Story Brick	0%	0%	0%	0%	0%	9%	14%
12								
13								
14	Average - 1 Story Riverine	0%	0%	0%	0%	9%	22%	30%

Figure D-7: Evaluated one-story single-family riverine DDFs

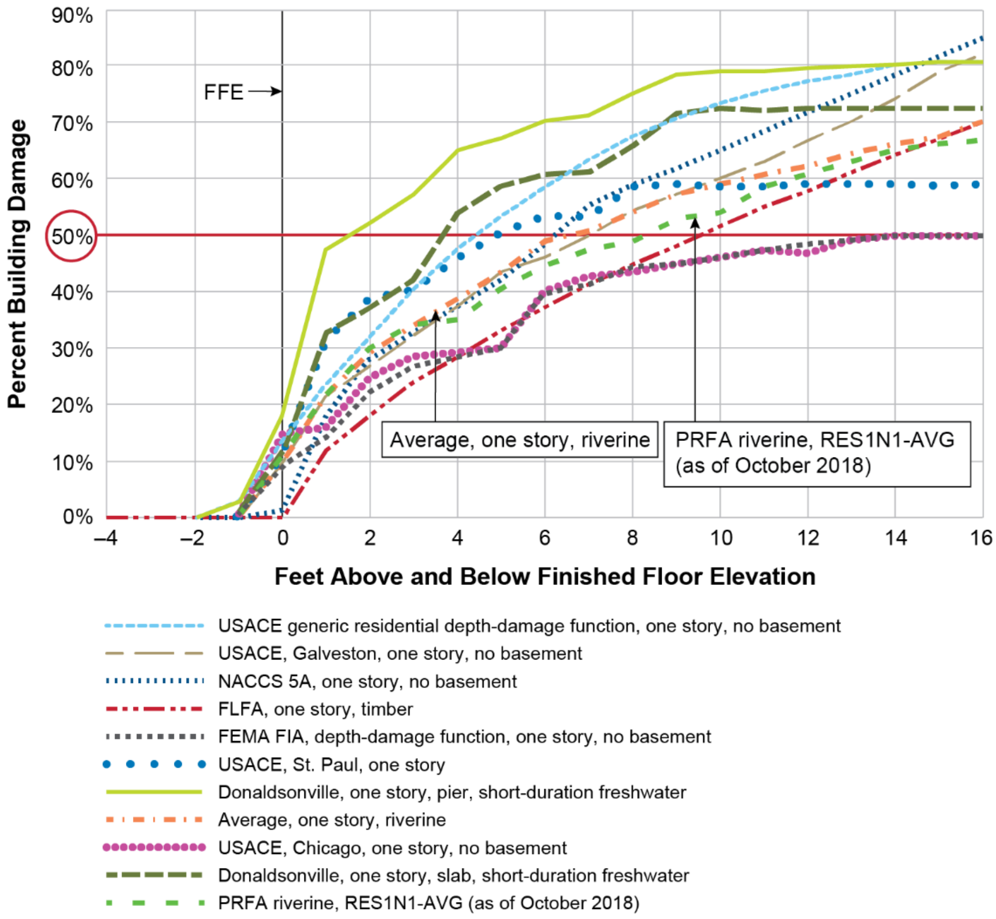


Figure D-8: DDFs for single-family, one-story dwelling, riverine condition

The next flood condition evaluated was one-story, single-family houses subject to saltwater inundation. A similar comparison was conducted using known saltwater inundation curves from a variety of sources. This was compared with the average freshwater inundation DDF to verify that at no point did the saltwater inundation DDF fall below the projected damage for the freshwater inundation DDF. Although the saltwater DDFs typically exceeded the freshwater DDF at low elevations, the saltwater DDFs did not always exceed the freshwater DDF at higher elevations. An analysis was conducted to evaluate the types of building components impacted by saltwater inundation on a per-foot-of-flooding basis. This analysis revealed that the corrosion of many metal building components should result in higher damages than the existing saltwater DDFs indicated. The increased density of saltwater also contributed to increased flood loads and building damages, particularly at lower elevations prior to the equalization of hydrostatic (standing water) loads on the interior and exterior of the building.

To meet the requirement that saltwater inundation DDF must continually exceed the freshwater inundation DDF, it was decided to evaluate the possibility of adjusting the freshwater inundation DDF to produce a realistic saltwater inundation DDF. Adjustments were tested from 110% (or a 10% multiplier applied along the entire freshwater DDF) up to 150% in 10% increments.

Comparing these results with the existing saltwater DDFs indicated that a 130% adjustment (30% multiplier applied to the freshwater DDF) produced a smooth, reasonable, and realistic saltwater inundation DDF for Coastal PFRA purposes.

Although the next flood condition to be evaluated based on damage severity would have been the moderate wave condition, it was decided instead that it would be more appropriate to evaluate the high wave condition next to avoid the potential for moderate wave condition damage to exceed the high wave DDF. It was decided to establish the high wave DDF, and then to estimate the moderate wave DDF based on the saltwater inundation and high wave DDFs.

Existing Zone V DDFs, which were similar to the high wave condition, were compared for a one-story single-family house on piles. These DDFs often needed normalizing to make sure that everything was referenced to the FFE, and that everything would be referenced by the wave crest elevation. Adjustments to these numbers allowed valid comparison of all the existing Zone V DDFs. Again, the approach of considering the different elevations for a one-story house on piles at which 50% damage and 100% damage occurs became a primary point of comparison. Further, it was discussed how much damage may occur below the FFE, and at what elevation to begin considering building damage, because damage to foundation members and floor framing is common in wave action. Based on this comparison, the FEMA Flood Insurance Administration (FIA) DDF for a Coastal V Zone building with an obstruction was selected as the most appropriate DDF. This DDF was further smoothed to avoid abrupt changes. Using this smoothed DDF, the building reached 50% damage at a depth of 2 feet above the FFE, but did not reach 100% damage until a flood depth of 10 feet. Although it is likely that 100% damage could occur at a lower elevation, it was difficult to force this without abrupt changes in the slope of the curve.

For a one-story single-family house on piles, the remaining flood condition to evaluate was the moderate wave condition that would apply to moderate wave conditions with sufficient wave heights to result in additional building damage beyond the saltwater inundation DDF. Although past disaster field studies have made clear that high waves can cause significant damage to wood-framed structures, it is more difficult to predict the damage associated with moderate waves. Although the type of damage done by moderate waves may be more severe depending on the foundation type (crawlspaces and some poorly designed shallow pier foundations may fail), these waves may not produce the same level of damage to floor systems as large waves, and are less likely to cause complete failure of wall systems.

Based on post-disaster evaluations, the moderate wave damages to a one-story single-family house on piles are expected to be between the high wave condition and saltwater inundation DDFs, and a little closer to the saltwater inundation DDF. Comparisons were made to the existing DDFs available using a similar approach, in which damage could equal a DDF for a more or less severe flood condition, but should not exceed damage for the more severe flood condition DDF, nor be less than the damage for the less severe DDF. Moderate wave potential DDFs were tested by creating moderate wave curves lying between the saltwater inundation and high wave DDFs, spaced at 10% increments of the damage difference between high wave condition and saltwater inundation damage. Based on this evaluation, it was decided the moderate wave condition DDF was best represented by using 30% of the difference between the saltwater inundation and high wave condition DDFs. This would skew the damages for moderate waves toward the saltwater inundation damage, yet still indicate an increase in damage from moderate waves.

Figure D-9 provides an overview of the comparison of DDFs for one-story single-family dwellings on piles. The 50% damage value is circled to show when the height above the FFE is reached.

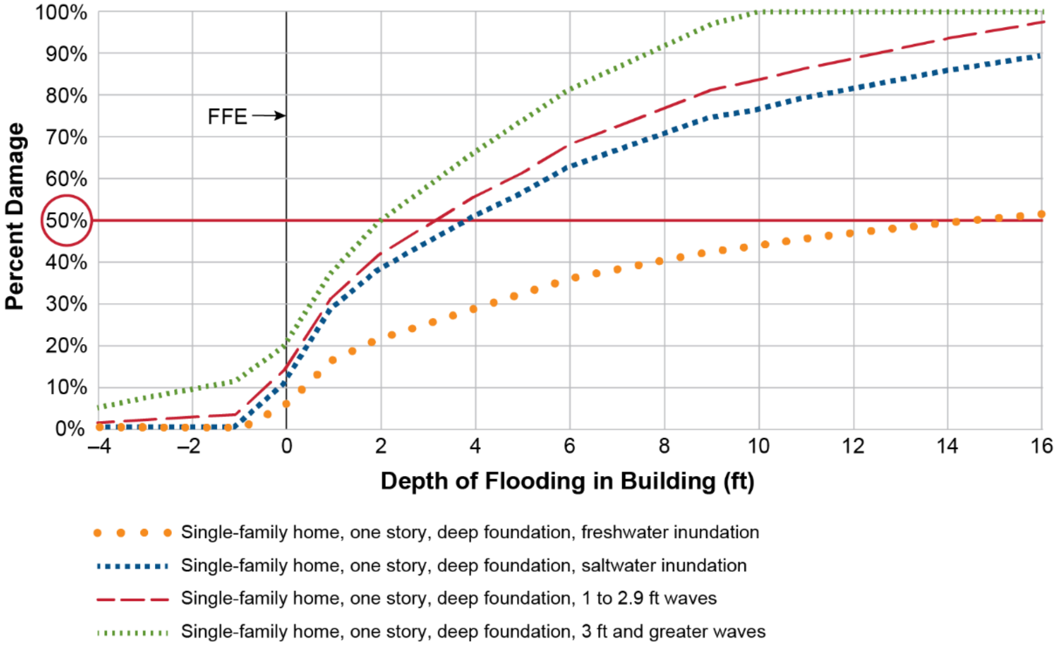


Figure D-9: Overview of one-story DDFs developed for the flood conditions that were evaluated

Initial Development of Two-Story Single-Family Coastal DDFs

Once the one-story single-family house DDFs were completed, the two-story, single-family house DDFs were considered. In most instances, it was anticipated that two-story single-family houses would accrue damage at a lower rate than one-story single-family houses. The only condition where the two-story house on piles DDF might exceed the one-story on piles is in the high wave condition, where large waves could damage the lower-story walls beyond the level at which they can support an upper story, resulting in the collapse of the structure. During the evaluation process, each two-story DDF was compared by flood condition with the corresponding one-story DDF, and a global comparison of all the two-story and one-story DDFs was made.

To conduct the evaluation of coastal flood damage to two-story single-family houses, it was necessary to assess what would be damaged per foot of flooding above the FFE using a similar approach to the one-story single-family house evaluation. Because many aspects of the mechanical, electrical, and plumbing (MEP) systems and kitchens are typically on the lower story, it was not assumed that a two-story house would accumulate damage at 50% of the rate of a one-story house. The evaluation of damage estimates revealed that when comparing two-story house building damage to one-story house building damage, a reasonable DDF could be created for a two-story house, based on a factored version of the one-story house DDF. After evaluating several factors, it was determined that calculating 75% of the one-story single-family “average” riverine DDF on a per-foot basis resulted in values that were similar and reasonable when compared to existing two-story single-family house DDFs. This approach had the added advantage of maintaining consistency in comparison between one-story and two-story houses for the freshwater inundation flood condition.

The two-story single-family saltwater inundation DDF was developed using the same methodology as the one-story single-family house, and the two-story freshwater inundation DDF was multiplied by 130% to calculate the saltwater inundation DDF. This two-story saltwater DDF was then compared with the one-story saltwater inundation DDF to evaluate the comparative damages, and the results appeared reasonable.

As discussed previously, the DDF for two-story single-family dwelling on piles in a high wave condition needed to be evaluated, with the additional consideration that when waves become high enough above the FFE, the first-floor walls could fail, and the additional weight of the second floor could cause a collapse of the entire structure. Consideration of post-disaster evaluations and knowledge of building systems resulted in the assumption that if wave crest elevations reached or exceeded 6 feet above the FFE, then the second story would collapse, and would result in 100% damage to the building. Damage comparisons between the one-story and two-story single-family house on piles with the high-wave DDFs were done at 1 foot, 2 feet, and 3 feet above the FFE, with the assumption that the two-story single-family house on piles would accrue damage more slowly than the one-story single-family house on piles. As a result of the comparisons, an estimate was made (for the two-story single-family house on piles) that 15% damage would likely occur when wave crests reached the FFE, and 45% damage would likely occur at 2 feet above the FFE. These values were then fit to the 100% damage anticipated at 6 feet, and a DDF was projected. Minor adjustments were made to the two-story single-family high-wave damage percentages to smooth out and finalize the resulting DDF.

Finally, a two-story single-family house on piles DDF was created for the moderate wave condition using a similar approach to the development of the one-story single-family house on piles moderate wave condition DDF. Based on a similar progression of calculating the difference between the two-story house saltwater inundation DDF and the two-story house on piles with high waves DDF, the DDF differences were tested using 10% increments. As with the one-story structure, the 30% value resulted in the DDF that best represented the predicted damage from moderate wave conditions applied to a two-story single-family house on piles.

Figure D-10 provides an overview of the DDFs selected for each of the flood conditions for two-story single-family houses on piles. The 50% damage value is circled to show the height above the FFE that this condition is reached.

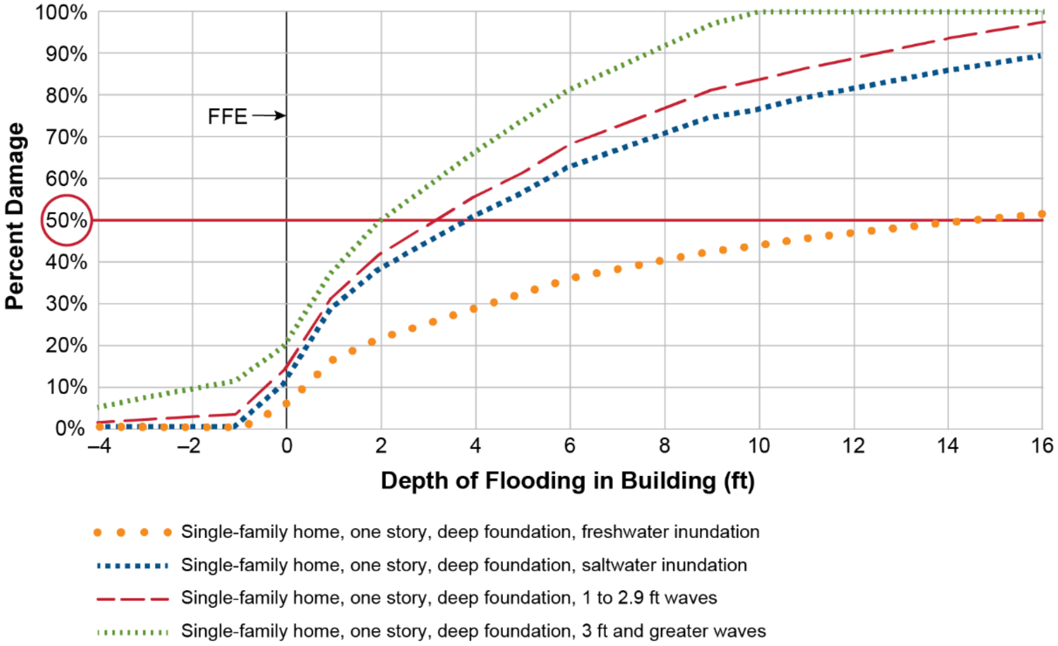


Figure D-10: Overview of two-story DDFs for each flood evaluated condition

Comparison of One- and Two-Story DDFs for Houses on Piles

Figure D-11 provides a comparison of both the one-story and two-story single-family house DDFs. The 50% damage threshold is highlighted with a circle and red line to show the height above the FFE at which each DDF reaches this threshold. Note that for the high waves flood condition, the damage for the two-story house on piles equals the damage for the high waves flood condition for the one-story house on piles at approximately 2.8 feet above the FFE; and beyond that height, the damage for the two-story high waves house on piles condition exceeds the one-story house on piles. This notable variance in the high waves flood condition DDFs is due to the anticipated increase in damage resulting from the collapse of the two-story house when the lower story is compromised by wave action.

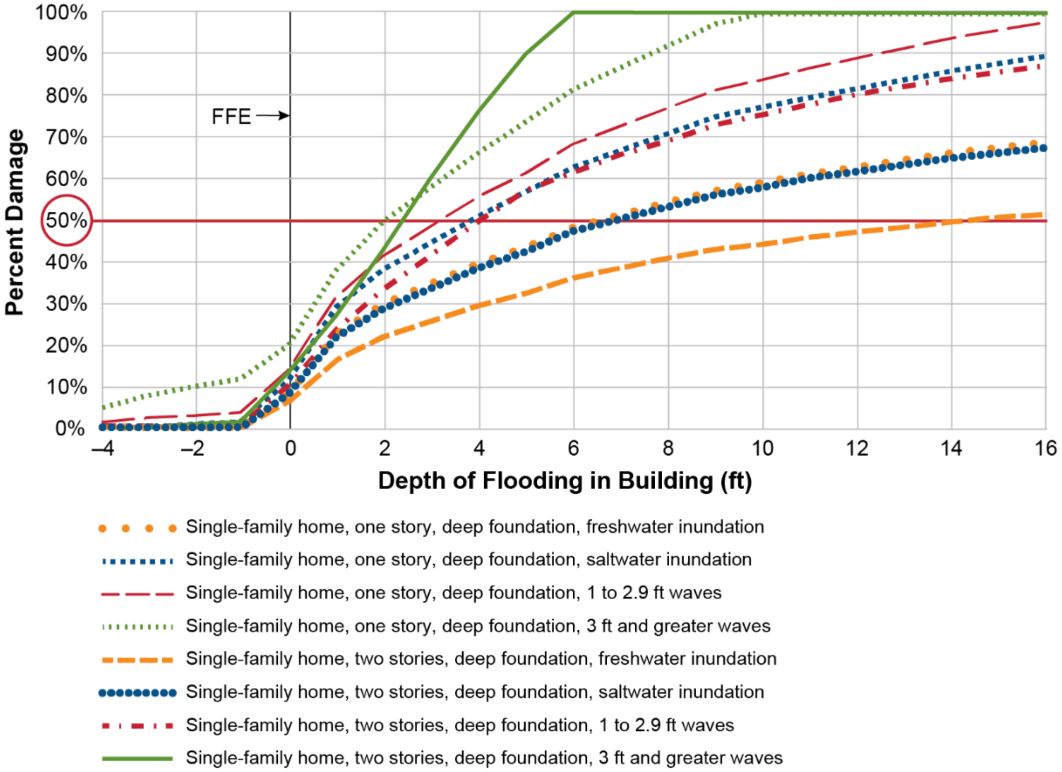


Figure D-11: Comparison of DDFs for one- and two-story single-family dwellings in various coastal flood conditions

Development of Additional DDFs

At the conclusion of the initial analysis of DDFs, it was determined that the initially developed DDFs were enough for houses on piles; however, on review of additional data, it was decided additional DDFs were necessary to address data sources that included foundation types and basement finishes. Post-storm evaluations indicated a primary factor in building performance in areas subject to wave action, and high flood velocities with foundations depth (shallow versus deep) and type (open versus closed). These factors are relatively easy to determine and verify with building stock. Using data provided for the Coastal PFRA task, the Coastal PFRA DDF Team defined a shallow foundation as short piers, crawlspaces, or slab-on-grade.

Piers are often constructed of masonry or potentially concrete, and sit on shallow footings either at grade or slightly below grade. These footings are commonly at significant risk of being undermined by scouring and/or erosion, and can rotate under wind and flood loads, causing the building to become unstable.

Crawlspaces are defined as closed foundations, usually consisting of masonry walls or poured concrete, with interior piers. Footings for these systems are also usually at grade or just below grade, and are commonly subject to scouring and/or erosion. The presence of openings is a topic to be investigated in the future for benefits to areas of saltwater and freshwater inundation. Performance in conditions of moderate waves or high waves will likely not improve significantly for crawlspaces compared to piles. The benefits of flood openings would still be applied in these locations under conditions of inundation.

Slab-on-grade construction is the final foundation type considered for shallow foundations. This is typically an unreinforced or minimally reinforced slab poured on the ground with thickened sections below the perimeter and under interior load-bearing elements. Thickened slab areas act similarly to footings and prevent the slab from cracking under vertical loads. Slabs are at risk of failure due to scour and/or erosion. Due to these slabs being lower than houses constructed on piers or crawlspaces, the initial damage above the FFE to the house would likely be inundation flooding, and then could have higher flood depths before wave action is experienced.

Basements consist of deep foundations, but are expected to perform differently from deep pile foundations in all flood conditions. The available data indicated a differentiation between finished and unfinished basements, and the decision was made to address both foundations in the development of DDFs. In inundation flooding, basement areas are expected to begin flooding as soon as floodwaters reach the building. These DDFs would acknowledge that damages would also accumulate prior to floodwaters reaching the FFE. In areas subject to moderate waves and high waves, basement area damages were predicted to accumulate more quickly to address the potential impact of scour and erosion; and in areas of high wave action, it is possible that significant structural damage would occur prior to floodwaters reaching the FFE. This condition was reflected in the DDF development.

Closed Foundations High Wave and Moderate Wave Conditions

Additional analysis was conducted for one- and two-story dwellings on shallow foundations (short piers, crawlspaces, or slab-on-grade). Dwellings with deep pile or shallow foundations should exhibit similar damage when exposed to freshwater inundation and saltwater inundation, because damage below the FFE should be minimal, and the likelihood of significant erosion and scour should be low, assuming water velocities are low enough to meet the coastal condition of no waves. DDFs, however, did need to be created for shallow foundations in areas subject to moderate and high waves.

To develop the two additional DDFs for shallow foundations, the same process was used as described previously for pile foundations, by estimating the high waves condition damage for a one-story single-family house, and then making sure that the moderate wave condition DDF was between the high waves and saltwater inundation DDFs. The analysis evaluated expected damage per foot of flooding for shallow foundations from a 3-foot or higher wave beginning at approximately 4 feet below the FFE, and up to 16 feet above the FFE.

The evaluation considered what type of damage these types of waves would do to a shallow foundation as compared to a deep foundation. Several existing DDFs were evaluated, and compared to those developed earlier for coastal one-story single-family houses. The DDF used for one-story single-family houses for deep foundations was adjusted 1 foot to take the percentage value at each foot and shift it to the next lower foot (e.g., an FFE of 0 foot at 20%

damage for deep foundations was shifted to -1 foot) to reflect the increase in damage associated with shallow foundations.

Because the damages for buildings in high waves accumulate quickly above the FFE, it was determined that this was an appropriate amount of increase. Note that for many shallow foundation buildings, by the time the wave heights reach 3 feet, the flooding will often be above the FFE of the building. To reflect the increased damage for shallow foundations subject to even small wave action, an increased factor was applied between the saltwater inundation DDF and the one-story single-family house DDF in high waves.

For a one-story single-family house on a shallow foundation subject to moderate waves, it was assumed that the damages would be 40% of the difference between the saltwater inundation DDF and high waves DDF. This reflects an increase from the 30% value (between the high waves and saltwater inundation DDF) used for a one-story house with a deep foundation subject to moderate wave action.

Figure D-12 illustrates the comparison of the one-story shallow foundation DDFs for moderate wave and high wave areas with the one-story deep foundation DDFs for the same areas. The DDF for saltwater inundation is also provided for comparison. The shallow foundation saltwater inundation DDF and deep foundation saltwater inundation DDF are identical.

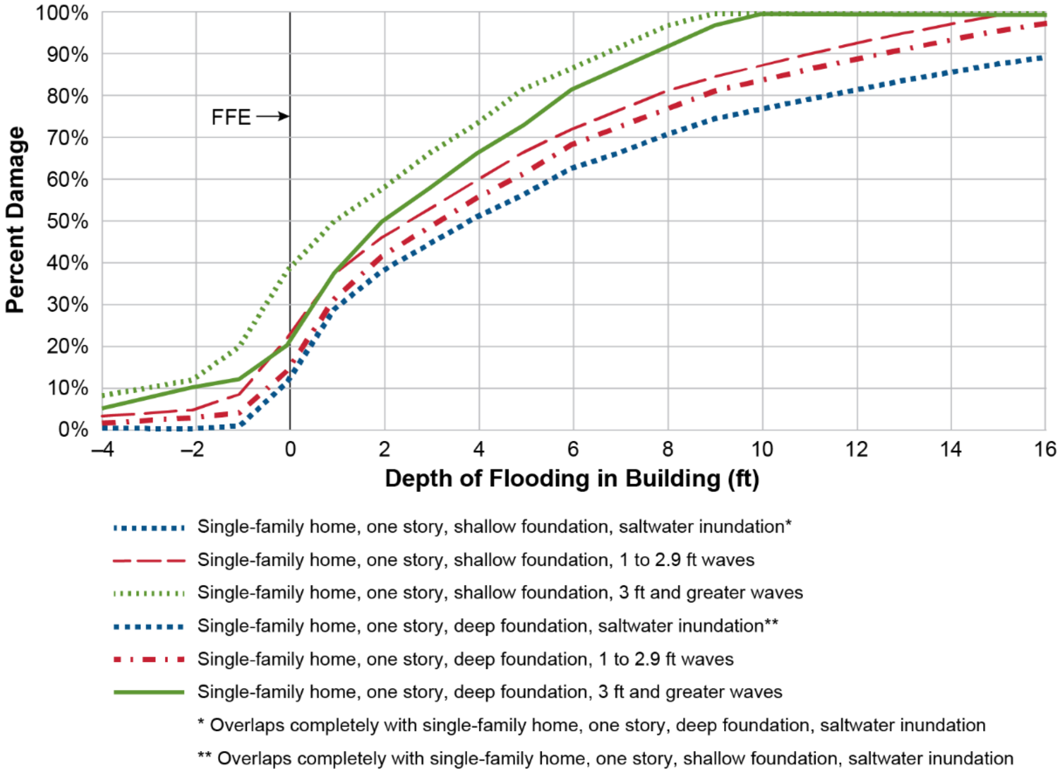


Figure D-12: Comparison of DDFs for one-story shallow foundations and one-story deep foundations for moderate and high wave conditions

The analysis of two-story single-family dwellings with shallow foundations followed a similar approach to the development of the one-story single-family dwelling DDFs. Initially, two-story single-family houses with shallow foundations were intended to be evaluated in high waves, considering specifically how these foundations would fail in a different manner than two-story deep foundation houses. However, several existing DDFs were evaluated for two-story houses, so the determination was made to treat the two-story houses in high waves in a similar manner to the one-story houses; that is, to use a 1-foot "downward" shift with the high wave DDF. This implies that, for example, the percent damage for the FFE is now used for the height 1 foot below the FFE, and each value from the initial two-story deep foundation DDF for high waves is shifted, with the house reaching 100% damage at 5 feet above the FFE, rather than the 6 feet used for the deep foundation DDF in high waves.

The same methodology was applied to the two-story single-family shallow-foundation moderate wave DDF that was used for the one-story shallow-foundation moderate wave DDF. The moderate wave DDF was taken to be 40% between the saltwater inundation DDF and the high waves DDF. This approach assumes that damages from moderate waves for a shallow foundation would be higher than saltwater inundation alone, but marginally skewed toward the inundation damage. This assumption was based on expert opinion, and lengthy discussion of how various shallow foundation building components would be damaged during a coastal flood event. Figure D-13 illustrates the comparison of two-story single-family DDFs for both shallow and deep foundations in high wave conditions and moderate wave conditions. The two-story single-family house saltwater inundation DDF is also shown for comparison, but the values are the same for both the shallow and deep foundations.

The analysis also conducted a comparison of the one-story shallow foundation DDF and the two-story shallow foundation DDF for the high wave and the moderate wave conditions. This comparison was conducted to evaluate whether one-story and two-story houses on shallow foundations were accumulating damage appropriately when compared against each other. This helped to satisfy one of the study's objectives; namely, to submit a suite of DDFs for AAL estimation that are consistent with one another based on differences in flood conditions, number of stories, and foundation depths/types. Figure D-14 provides a comparison of the DDFs for one-story single-family houses on shallow foundations, and two-story single-family houses on shallow foundations for high waves, moderate wave action, and saltwater inundation. Note that the percent damage for shallow foundations accumulates more rapidly per foot of damage for the two-story house, similar to one-story and two-story single-family houses with deep foundations. This increase in damage is due to the increased likelihood that with damaged first-floor wall systems that support the second story of a house, the house would collapse onto the first story.

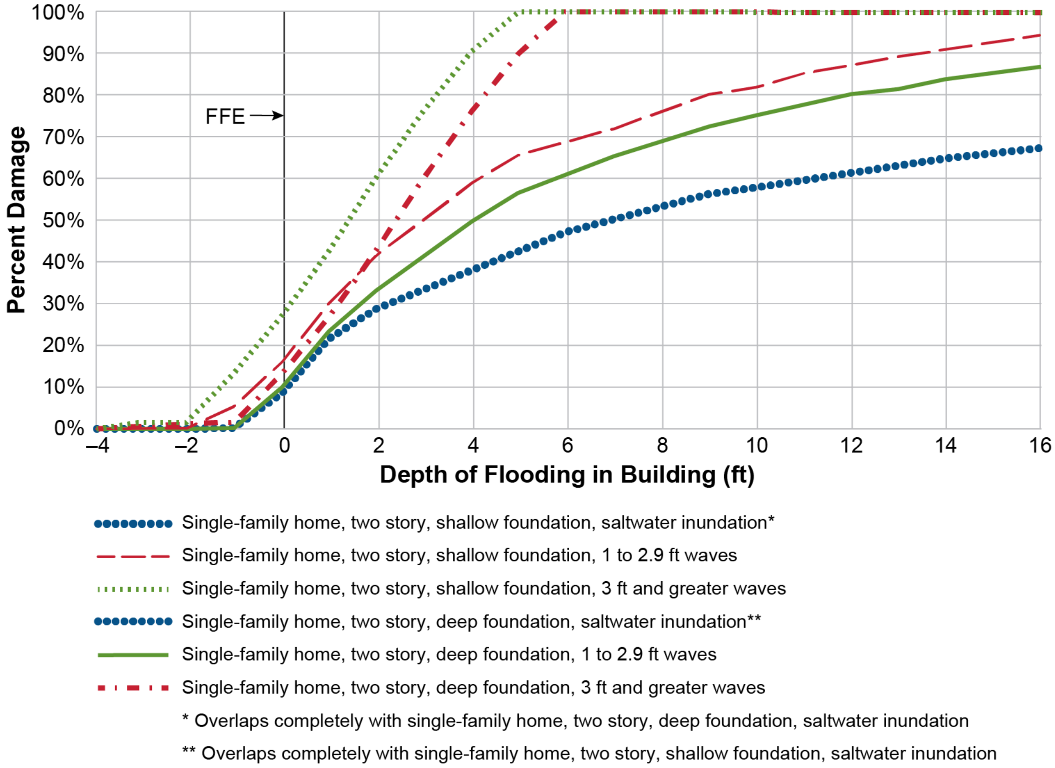


Figure D-13: Comparison of DDFs for two-story shallow foundations and two-story deep foundations for high waves, moderate wave, and saltwater inundation conditions

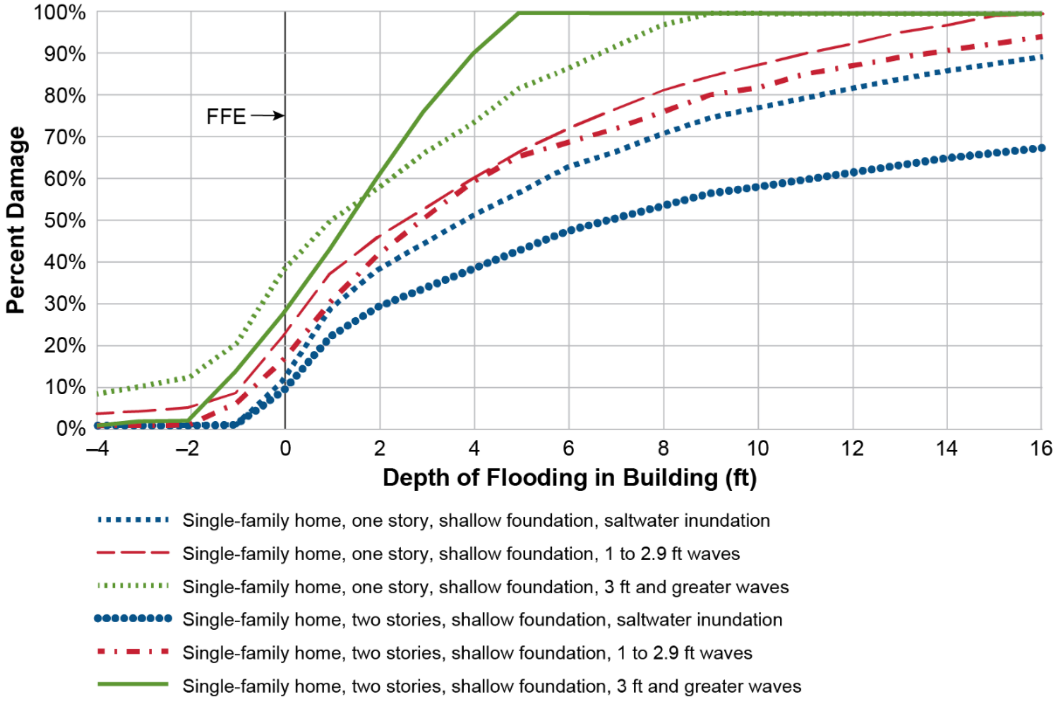


Figure D-14: Comparison of DDFs for one- and two-story shallow foundations for high waves, moderate waves, and saltwater inundation

Basement Foundations Subject to Flooding

One- and two-story single-family houses with basements were addressed by developing DDFs for each flood condition: from freshwater inundation to saltwater inundation, from moderate waves to high waves. Finished and unfinished basement conditions were evaluated to recognize the higher damages associated with finished areas below grade. Basements were assumed for analysis purposes to meet the NFIP definition of being below grade on four sides. An additional assumption was that the "ground" floor of the house would be 2 to 3 feet above exterior grade, and that basement flooding would begin when water was 2 feet below the FFE (by entering through a window well or door well). While current construction practices extend window wells to the ground floor elevation, the assumption of flooding beginning 2 feet below BFE was assumed to represent the majority of the floodplain construction not built current practices, especially pre-FIRM structures. Flood damage was limited to that caused by overland flooding, and not to groundwater intrusion, so aboveground floodwater had to reach the area surrounding the building before basement flooding would begin. Although damage would begin to accrue at −2 feet, this assumed the basement would immediately be filled with 7 feet of water; prior to that time, damages were assumed to be zero, but after that time the basement would flood immediately. This approach was slightly modified for high waves and for moderate waves.

Historically, many DDFs have assumed that basement areas for one-story houses should be considered as a two-story house, and the DDF just shifted to the lower (basement) floor elevation. However, this approach neglects the fact that first floors of houses typically include the kitchen, and usually half baths that include vanities and finishes of a higher quality than even finished basements. To determine the cost and value of a basement, RSMeans Costworks was reviewed to determine the percent change in the construction costs for incorporating a basement into a building, particularly finished basements. The analysis considered that with an unfinished basement, during inundation flooding conditions, the structural system would not be damaged by floodwater; the costs associated with a basement damage would primarily be related to damaged water heaters, furnaces, etc., plus the cost to clean the basement area. Finished basements would include the cost of interior partitions; insulation; wall, floor, and ceiling finishes; and minor electrical, mechanical, and plumbing work.

When developing the DDFs, the analysis considered that at a depth of 1 foot below the FFE, the basement area would be completely submerged with floodwater, filling the entire depth of the basement (from the basement floor up to the ceiling or bottom of the joists for the next floor). The findings from the RSMeans Costworks analysis were applied to the full height flooding for finished and unfinished basement conditions. For the freshwater and saltwater inundation conditions, adjustments were made to the percent damage to a height of 2 feet below the FFE (when water first enters the basement); and at 3 feet below the FFE, it was assumed there was no damage (no water had entered the basement yet). The difference between 1 foot below FFE and 2 feet below FFE is minimal, given that floodwater heights this deep inside a basement area would require approximately the same amount of repair (complete inundation).

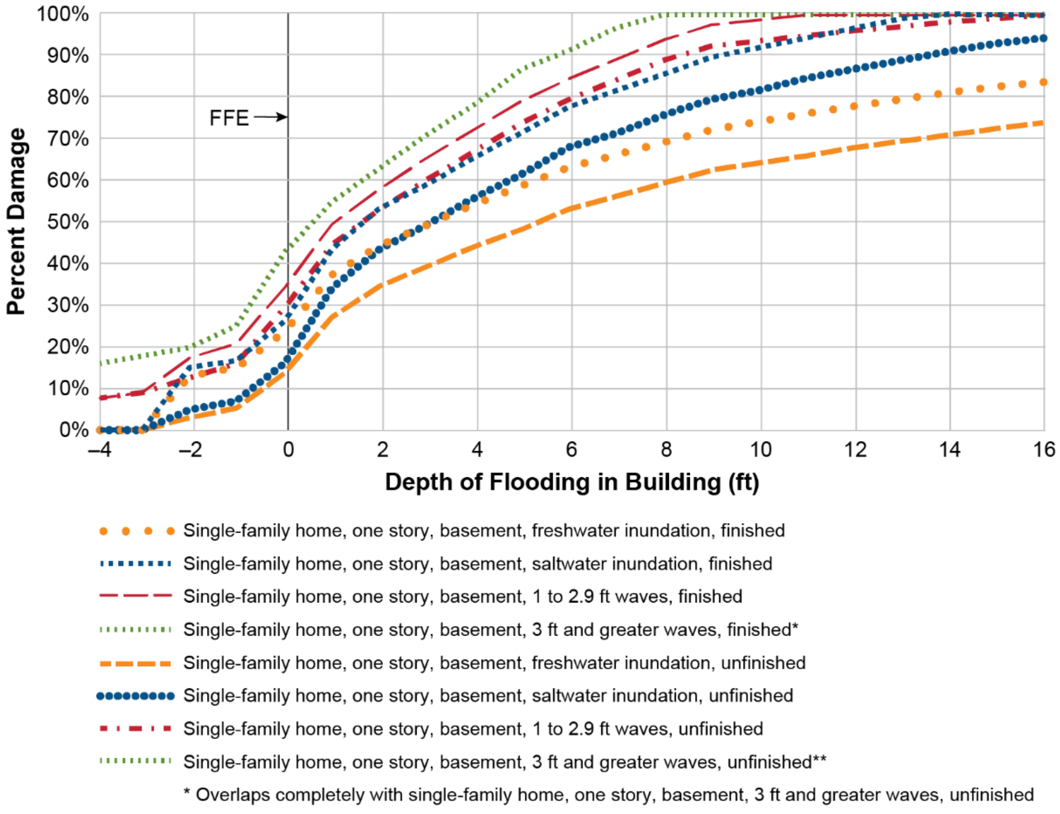
Once the damages for full-height basement flooding were established, the percent damage for the fully inundated finished and unfinished basement foundations were simply added to the average freshwater inundation percent damage values for the FFE, and above that were assigned for one-story single-family houses. The same approach was used for developing the saltwater DDF for the one-story single-family finished and unfinished saltwater inundation for the FFE and above.

Next was the evaluation of high wave condition for basement foundations. There was significant discussion of how damage would occur to basements in high wave conditions. The assumption was that a basement could be situated in an older house on top of an erodible dune or other feature where either scour or erosion could expose a basement wall to wave action. In this scenario, it was assumed high waves would not only flood the basement, but also would cause structural damage to basement walls. This type of damage is more expensive than inundation damage alone, and most costs associated with repairs would be the same for both a finished and unfinished basement. As a first approximation, it was decided that in high wave conditions, finished and unfinished basements should be treated the same, with no differences in the percent damage. Damages would be assumed to accumulate more rapidly per foot of flood depth than in a shallow foundation exposed to high wave conditions.

Conditions with moderate wave action were addressed in a similar fashion to the development of the DDF for houses with deep and shallow foundations, by calculating damage due to moderate waves between saltwater inundation and high wave conditions. The with-basement moderate wave DDF was taken to be 50% between the saltwater inundation and the high wave DDFs.

Figure D-15 provides a summary of the one-story basement foundation DDFs created for all flood conditions evaluated: freshwater inundation, saltwater inundation, moderate wave conditions, and high wave conditions. The DDFs for both finished and unfinished basements are shown. The DDFs for the one-story single-family houses with finished and unfinished basements are identical. In the areas of moderate wave conditions, the values at 4 feet below FFE and 3 feet below FFE are identical percent damage values because the high wave conditions are the same for both finished and unfinished basements; and in the inundation conditions, it is assumed that floodwater would not have reached the basement yet. At depths of 2 feet below FFE and higher, the percent damage values in areas of moderate wave conditions for finished basements increase more quickly than unfinished basements because the values for finished basements subject to saltwater inundation were higher than unfinished basements.

Figure D-16 provides a comparison of one-story single-family houses on shallow foundations and one-story single-family houses with unfinished basements. The one-story single-family houses with finished basements are not shown to avoid an overly complex graphic. The calculated shift can be observed in the percent damage for one-story single-family houses with either unfinished basements or finished basements in areas of saltwater inundation and freshwater inundation, as previously described in the assigned percent damage values. Figure D-16 also illustrates that, in each of the flood conditions, the analysis expected single-family houses with basement foundations to accumulate damages more quickly than shallow foundation buildings. This is consistent with the overall approach to the development of the DDFs. The overall approach also sought to minimize abrupt changes in damage percentages, unless some aspect of the building type/foundation or flood condition could reasonably cause such a change.



* Overlaps completely with single-family home, one story, basement, 3 ft and greater waves, unfinished

** Overlaps completely with single-family home, one story, basement, 3 ft and greater waves, finished

Figure D-15: Comparison of DDFs for one-story basement foundations – finished and unfinished, for high waves, moderate waves, saltwater inundation, and freshwater inundation

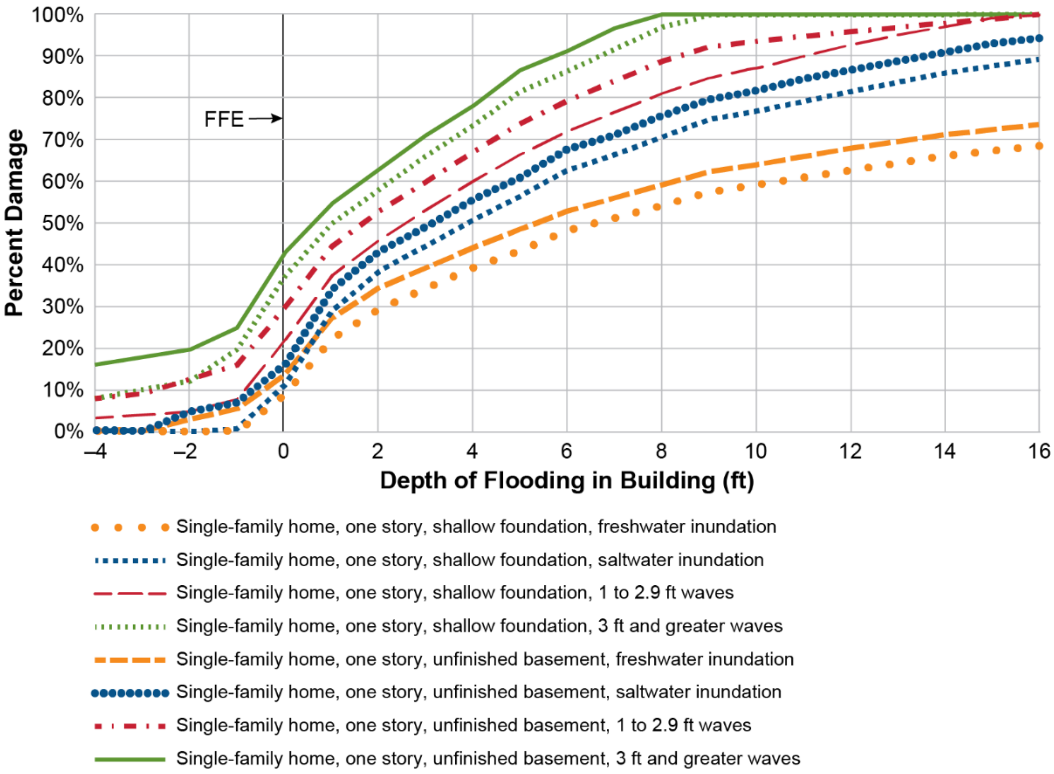


Figure D-16: Comparison of DDFs for one-story shallow foundations and one-story basement foundations – unfinished for high waves, moderate wave conditions, saltwater inundation, and freshwater inundation

The evaluation of DDFs for two-story single-family houses with basements was very similar to the development of the one-story single-family houses with basements. Initially, a comparison of the cost to include a two-story finished and unfinished basement was determined using RSMeans Costworks. The difference in the percentages between a finished and unfished basement was calculated and applied as part of the finished basement damage calculation. A determination was made regarding the amount of damage that would occur with freshwater inundation to the full height of a finished and unfinished basement for a two-story single-family house. These percentage values for full-height basement inundation were just added to the already calculated percent damage values used for two-story single-family houses with either shallow or deep foundations. The same approach was used to create DDFs for finished and unfinished basements for two-story single-family houses subject to saltwater inundation.

Two-story single-family houses with finished and unfinished basements were evaluated for high wave conditions using procedures and assumptions like the one-story single-family house scenarios, which assumed that in conditions of high waves, the damage to basement areas would be largely structural. It was assumed that in high wave conditions, the differences in performance between the finished and unfinished basements would not be significantly different, so the same percent damage values were applied. Like the previous assumptions regarding performance for high wave condition in single-family two-story houses, it was assumed that the waves would also collapse the two-story house at a lower height above the FFE than the one-story single-family house DDF.

The final set of DDFs necessary to develop were the two-story single-family houses with finished and unfinished basements in areas of moderate waves. Like the one-story single-family houses with basements, the moderate wave DDF was assumed to be 50% of the way between the saltwater inundation and high waves DDFs. Figure D-17 shows the comparison of the two-story single-family houses with finished and unfinished basements in freshwater and saltwater inundation, areas of moderate waves, and high wave conditions. The application of the moderate wave action condition is less noticeable in the two-story finished and unfinished basement values because initially, the high wave condition for two-story house with basements accumulates damage less quickly than the one-story houses with basements. The high wave values for both finished and unfinished basements are the same; and for saltwater inundation, the values of 2 feet below the FFE and 1 foot below the FFE are not significantly different for finished basements (because the basement is completely inundated). The difference is larger for unfinished basements in areas of moderate wave conditions because the percent damage is lower for the saltwater inundation condition.

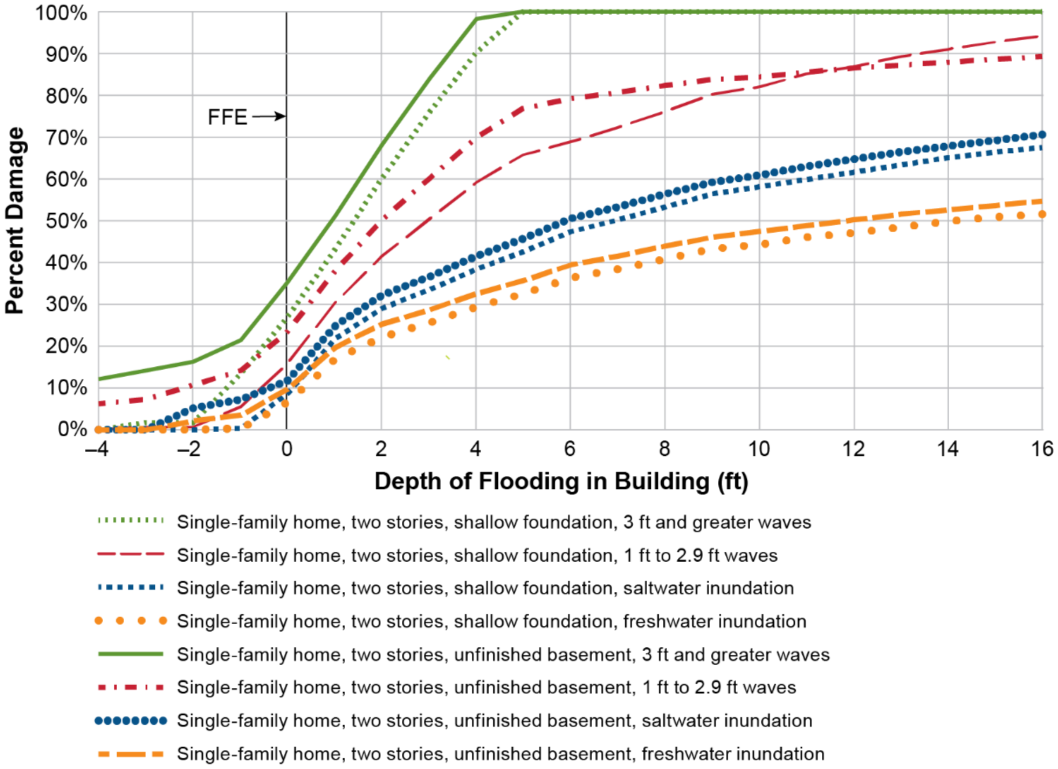


Figure D-17: Comparison of the DDFs for two-story basement foundations – finished and unfinished for high waves, moderate waves, saltwater inundation, and freshwater inundation

Figure D-18 provides a comparison of one-story single-family houses with unfinished basements and two-story single-family houses with unfinished basements. Similar to the shallow and deep foundation comparisons of one-story and two-story houses, the DDF for the one-story house initially shows higher percent damage values than the two-story house; but because it was assumed that the two-story house would collapse at a lower flood level above the FFE, the two-story percent damage accumulated more quickly than the one-story.

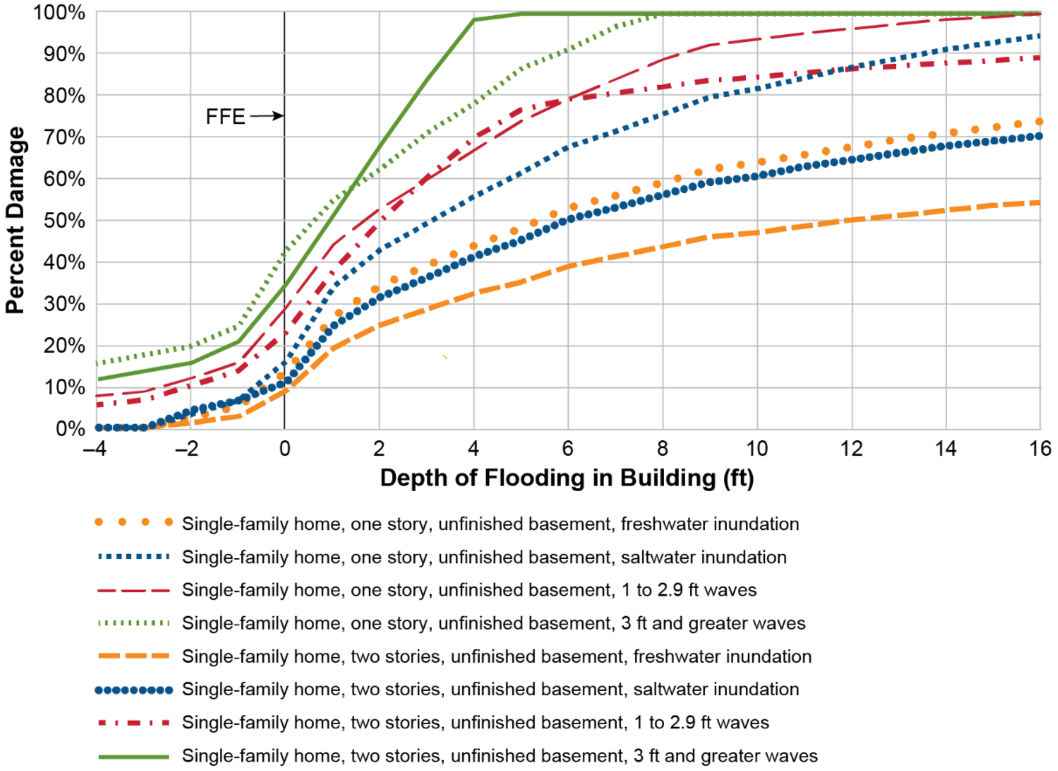


Figure D-18: Comparison of DDFs for one-story and two-story unfinished basement foundations for high waves, moderate waves, saltwater inundation, and freshwater inundation

Figure D-19 provides the final comparison of basement DDFs developed for two-story single-family houses and two-story shallow-foundation DDFs, for freshwater and saltwater inundation, areas of moderate waves, and high wave conditions. The comparison of the shallow foundations to unfinished basements in two-story single-family houses is consistent with the approach used to compare the same foundation types in one-story single-family houses. In each case, the unfinished basement foundation accumulates damage more quickly than the shallow foundation. This is consistent with the concept that foundations experience more risk accumulating damage at lower heights in relation to the FFE, and this occurs for each flood condition. Similar comparisons could be shown for shallow foundations and finished basements, with percent damage values higher for finished basements than unfinished basements for both the inundation condition and the moderate wave action condition.

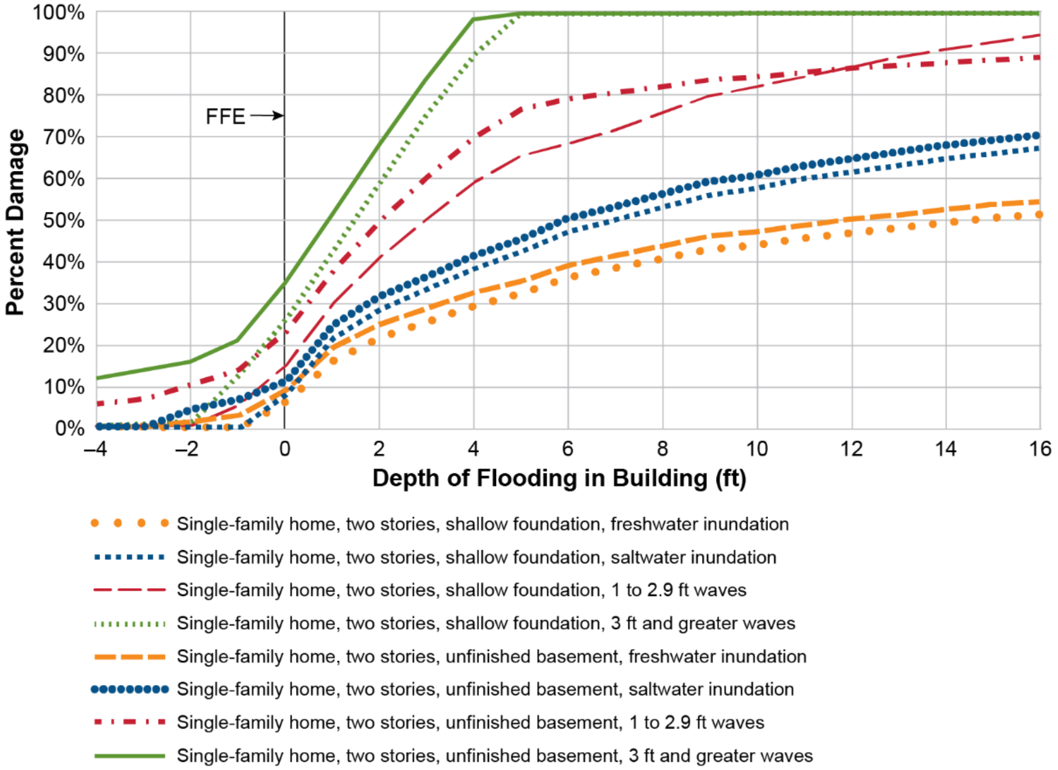


Figure D-19: Comparison of DDFs for two-story shallow foundations and two-story unfinished basement foundations for high waves, moderate waves, saltwater inundation, and freshwater inundation

D.3.2.2 Non-Residential DDF Development

In addition to the DDFs for single-family dwelling (RES1) structures, the flood analysis also developed DDFs for seven additional common occupancy types. These seven new DDFs were for Apartment, Office one-story, Office three-story, Retail, Hospital, School, and Police. For each of these seven occupancy types, a similar process was used to develop a family of four DDF curves ranging from freshwater riverine inundation, no wave saltwater inundation, 1- to 2.9-foot-wave saltwater inundation, and 3-foot and greater waves saltwater inundation. Comparisons were made between existing DDFs from riverine flooding for each new occupancy type, and an "average" curve was developed considering any adjustments for FFE. Next, the highest wave condition curve was developed, and then the other two curves were developed by scaling between the riverine and high wave curves. As with the RES1 DDF, only the freshwater riverine and the high wave DDFs were used in this LAS for Zone A and Zone V, respectively.

Besides these new curves, this LAS also made use of the default Hazus DDFs for occupancies COM10 (Parking Deck), IND1 (Heavy Industrial), and IND2 (Light Industrial).

D.3.2.3 Contents DDF Development

The new DDFs developed for this study focused on the structure damages. To model contents damage, companion contents damage curves had to be developed for each structure DDF. For the new RES1 curves, a review of existing residential contents curves found that, on average, the contents sustain 40% more damage than the structure for a given flood depth. For example, if a structure damage curve has a value of 10%, the contents damage curve would equal 14%. This 40% adjustment factor was used to develop all new RES1 contents DDFs, keeping in mind contents damage is capped at 100%.

For the new non-RES1 DDFs, approximate content values were calculated from 0 to 8 feet. Contents damage was assumed to be the same from 8 to 10 feet; and for multi-story buildings, would begin to increase again once floodwater reached the next story. Curves were calculated based on some initial data breakpoints, based on assumptions, and then a polynomial fit curve was developed for other flood depth. For light-framed buildings in Zone V areas, damages increase more quickly because waves are assumed to damage building walls, and this was assumed to estimate damage for all interior contents. Depending on the structure type (and underlying assumption of number of stories), the maximum contents damage for the range of flood depths modeled (up to 10 feet deep) was capped at 100% (one-story), 50% (two-story), or 30% (three-story or greater).

D.4 Data Quality

This section provides additional information to supplement Section 4.4 in the main BCS Study report, specifically focused on data quality issues briefly described at the end of the section.

The prior discussion in Section 4.4.2 on IBC structures is one example of how the data quality and analysis assumptions for the flood analysis typically resulted in this study underestimating potential AALA. The various data sources had limitations that often resulted in no data or incomplete data that were queried out of the analysis. For example, the CoreLogic source data had missing data and data gaps for portions of Alaska, North Dakota, and South Dakota; and major data gaps in Illinois, Louisiana, Michigan, Minnesota, New Mexico, and Wisconsin. Likewise, even when CoreLogic did include data fields, like those for foundations or number of stories, often they were sparsely populated.

The methods used to turn parcel data into structure data also had limitations, as discussed earlier, especially for multi-unit structures where a large number of parcel records had to be transformed into small number of structures. Because the flood analysis was highly dependent on spatial analysis to determine what structures were in the floodplain, having problematic data associated with multi-unit structures likely may have produced some structure data that could use further refinement to better reflect the actual built environment. Although limited data filtering was performed for obvious outlier or errors in the source parcel data, it is likely there are some clusters of multi-unit parcels that may have not been fully reconciled into a structure format.

Specific to the flood analysis, data quality control found that the source FEMA community boundary data for both NFIP communities, and also for the BCEGS community designations, had numerous Geographic Information System (GIS) topological and data quality issues. For those states that had adopted statewide freeboard in 2000 or earlier where close to 100 percent of structures with freeboard would be expected, most states typically had around 95% with freeboard. In some states, this may have been legitimate if the analysis found a structure in the floodplain of a non-NFIP participating community. Even though the surrounding state would have mandatory freeboard adoption, these non-participating communities would not be expected to enact freeboard requirement. However, spot checks of data in the flood analysis also found topological issues in the source FEMA community data that would not properly assign a required spatial ID during a GIS analysis. Most states required some level of FEMA community boundary cleanup to perform the flood analysis, and likely small percentages of structures may have been excluded from the analysis due to these issues.

A similar issue related to spatial data lookups and data quality also was seen near coastlines or large waterbodies where source data used for Census tract and block assignment may have had issues if structure locations, especially those based on parcel centroids, were located in a waterbody that might have been clipped out of the source data. Alternative GIS spatial analysis methods were used to assign values for these cases, where the “nearest” polygon was used for assignment rather than an “intersecting” polygon.

The use of Hazus and Hazus-based DDFs also was a data quality challenge for the analysis. As mentioned in previous discussions, the choice of modeling only freeboard to denote local flood code adoptions was based on both modeling and data availability. Other features of the IRC and IBC beyond the NFIP minimums standards for practices like elevated utilities, breakaway walls, and non-residential floodproofing were not included in this study. Likewise, the Hazus DDFs only corresponded to structure and contents damage, and did not include other direct-loss categories such as displacement, loss of function, and business and wage loss. Likewise, indirect impacts to short-term and long-term economic sectors were not modeled. The AALA value provided for the flood analysis can be thought of as a lower-bound analysis, where most assumptions have tended to underestimate losses avoided. This underestimate assumption also applied to not modeling manufactured housing as part of this study.

There are some assumptions that may have contributed to slight overestimations of losses avoided. Certain IBC structure types, such as certain agricultural structures, were assumed to have freeboard, while most IBC adoptions do not require freeboard for these types of structures. The use of the most recent FEMA NFHL floodplain boundary data, and not trying to replicate the changing nature of floodplains from 2000 to 2018, likely introduced errors by including structures in the floodplain that were not in the boundary when they were built, or excluding buildings that had been in the floodplain during construction, but are now out of the floodplain. Although previous studies did spot checks of these issues and found that they tend to balance out; in any given community, the floodplain change may be drastic enough that this study may have included too many structures.

A related source of possible overestimation is assumptions about local freeboard adoption. Although this study included all structures designated in the SFHA on FEMA maps, communities have been known to exclude certain flood zones from freeboard requirements, especially in communities with flood protections such as levees. It was beyond the scope of this study to be able to examine local-level ordinances for the exclusions of certain zones from the freeboard requirements being modeled.

This leads to the last main source of possible overestimation, which is general lack of local ground truthing and information on enforcement. This study assumed that if source documents indicated freeboard adoption, then all floodplain structures required to install freeboard were constructed with freeboard. Without some level of ground truthing or spot checking, this assumption of 100% installation is likely an overestimate. Although the level of this overestimate is likely small compared to underestimates like major portions of states with missing or incomplete data, future studies should look into developing ways to quantify enforcement estimates, and include adjustments for these types of studies.

APPENDIX E:

Wind Hazard Methodology Details

E.1 Supplemental Information for Wind Code History

This section provides additional details on the building code timelines for wind design provided in Table 5-2 and Table 5-3. The first subsection lists the hurricane wind hazard study area states in which there were no significant amendments enacted during the period of interest to weaken the wind design provisions in the adopted model building codes. The subsequent subsections discuss the unique aspects of the building code histories in the states where building code adoption was not mandated or enforced statewide. The final subsection discusses the states in which community-level data (ISO, 2018a) was used to model the building code history.

E.1.1 Hurricane Wind Hazard Study Area States with No Significant Wind Design Amendments to Model Codes

As discussed in Chapter 5, 22 states and Washington, DC, were modeled to compute the losses avoided. Of these hurricane wind hazard study area states, the following states adopted building codes on a statewide basis, as shown in Table 5-2 and Table 5-3, and did not enact amendments to significantly weaken their adopted model building codes:

- Washington, DC
- Florida[1]
- Massachusetts[2]
- Maryland
- Maine[3]
- New Hampshire
- New Jersey
- New York
- Pennsylvania
- South Carolina
- Vermont[4]
- Virginia

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[1] Florida adopts and enforces the FBC and FBCR, which are based on the IBC and IRC, but have some provisions that make them stronger than the IBC and IRC (e.g., High Velocity Hurricane Zone provisions).

[2] Massachusetts specifies design wind speeds by community in a tabular format. The specified design wind speeds are similar, but not identical, to those obtained from the ASCE 7 wind maps used for this study. In coastal areas, commercial buildings will have the same or slightly higher wind speeds than ASCE 7, but residential buildings will have slightly lower wind speeds that ASCE 7. Therefore, the ASCE 7 design wind speeds used for this study may slightly underestimate losses avoided for commercial buildings, and overestimate losses avoided residential buildings.

[3] In Maine, building code adoption and enforcement is only required in communities with populations greater than 4,000.

[4] Vermont adopts and enforces model codes for commercial buildings only (e.g., IBC) with no amendments.

E.1.2 Connecticut

Connecticut amended the IRC 2003 to reduce its Wind-Borne Debris Region (WBDR) to include only areas in which the design wind speed was at least 120 mph. However, for its adoption of International Building Code® (IBC®) 2003, it did not amend the WBDR. For its adoption of the International Residential Code® (IRC®) 2009 and IRC/IBC 2012, Connecticut provided a list of communities located south of I-95 that are defined to be in the WBDR. The exception to this defined WBDR was that areas more than 1 mile from the coast can be certified to be outside the WBDR by a professional. Therefore, the WBDR in Connecticut was modeled to only include buildings within 1 mile of the coast for its adoption of IRC 2009, 2012, and IBC 2012.

E.1.3 Delaware

Delaware does not adopt model building codes on a statewide basis. However, each of Delaware's three counties (Kent, Sussex, and New Castle) adopt model building codes. The code adoption time lines for the three counties are shown in Table 5-2 and Table 5-3. The three counties have not enacted amendments to weaken their adopted model building codes.

E.1.4 Hawaii

Hawaii was the only hurricane wind hazard study area state that adopted the Uniform Building Code (UBC) prior to adoption of the I-Codes. Although the state now requires each county to adopt the model code adopted by the state, it gives each county up to 2 years to do so. As noted in Table 5-1, the Hawaii state building code, which for this study was presumed to be applicable to all buildings with years built from 2013 to 2018, includes microzoned topographic speed-up, wind directionality (Kd), and exposure maps to be used for wind design. However, digital versions of these microzoned maps, suitable for used with GIS software, were not available for this study. Therefore, the design wind speeds for all post-2000 construction in Hawaii are assumed to be the wind speed shown in Figure 5-2 for UBC designs (i.e., 80 mph, fastest mile) or Figure 5-3 for 2003 or 2006 IBC or IRC designs (i.e., 105 mph, peak gust). This assumption will tend to understate the losses avoided for 2013-2108 buildings located in microzoned areas with combined topographic speed-up and wind directionality factors greater than 0.85. In addition, all buildings with years built from 2013 to 2018 are presumed to have been designed as inside the WBDR with opening protection. This assumption will overstate losses avoided for buildings designed as partially enclosed (i.e., without opening protection), which is permitted in cases where a safe room has been included in the building design.

E.1.5 Louisiana

Prior to Hurricane Katrina (2005), Louisiana did not adopt or enforce a statewide building code, and BCEGS (2018) does not have code adoption or enforcement data for any jurisdictions within the state. In 2006, however, the state began adopting and enforcing the IRC and IBC on a statewide basis. The building code histories for Orleans, Jefferson, and Plaquemines Parishes, up to adoption of the statewide codes in 2006, were found in post-disaster investigation reports published following Hurricane Katrina.

E.1.6 Mississippi

Mississippi adopts building codes at the state level, but local adoption and enforcement is optional. In addition, BCEGS (2018) does not have code adoption or enforcement data for any jurisdictions within the state. The building code histories for the three coastal counties of Jackson, Harrison, and Hancock were determined from post-disaster investigation reports following Hurricane Katrina. For all other counties in Mississippi, it was assumed that there was no building code enforced. In such cases, existing Hazus Wind Building Characteristic (WBC) distributions were used to model expected hurricane wind losses instead of overriding the default WBC distributions with specific characteristics inferred from building code requirements.

E.1.7 North Carolina

North Carolina amends the IRC and IBC to define its WBDR as “Areas within hurricane prone regions defined as that area east of the Inland Waterway from the North Carolina/South Carolina state line north to the Beaufort Inlet and from that point to include the barrier inlands to the North Carolina/Virginia state line.” This amendment reduces the WBDR area, and hence losses avoided, compared to the WBDR area from either the ASCE 7-98 or ASCE 7-10 wind maps.

E.1.8 Rhode Island

The building code adoption time lines for Rhode Island are shown in Table 5-2 and Table 5-3. Prior to 2015, Rhode Island reduced its WBDR to include only Rhode Island wind zone 3 (120 mph). In 2015, the definition of the WBDR for commercial buildings was changed to that defined by the IBC 2012. A corresponding change in the WBDR definition for one- and two-family dwellings (IRC) does not appear to have been enacted by the state. Rhode Island has also maintained the partially enclosed design option for one- and two-family dwellings in the WBDR. This partially enclosed design option amendment does not apply to other occupancies.

E.1.9 BCEGS States

As discussed in Chapter 5, there are five states in which code adoption and enforcement have been modeled at the local jurisdiction level using ICS (2018a) data: Alabama, Georgia, Texas, Vermont, and West Virginia. For Vermont, the BCEGS modeling approach is only applicable to one- and two-family dwellings (i.e., residential), but the other four states it is applicable to both residential and commercial buildings.

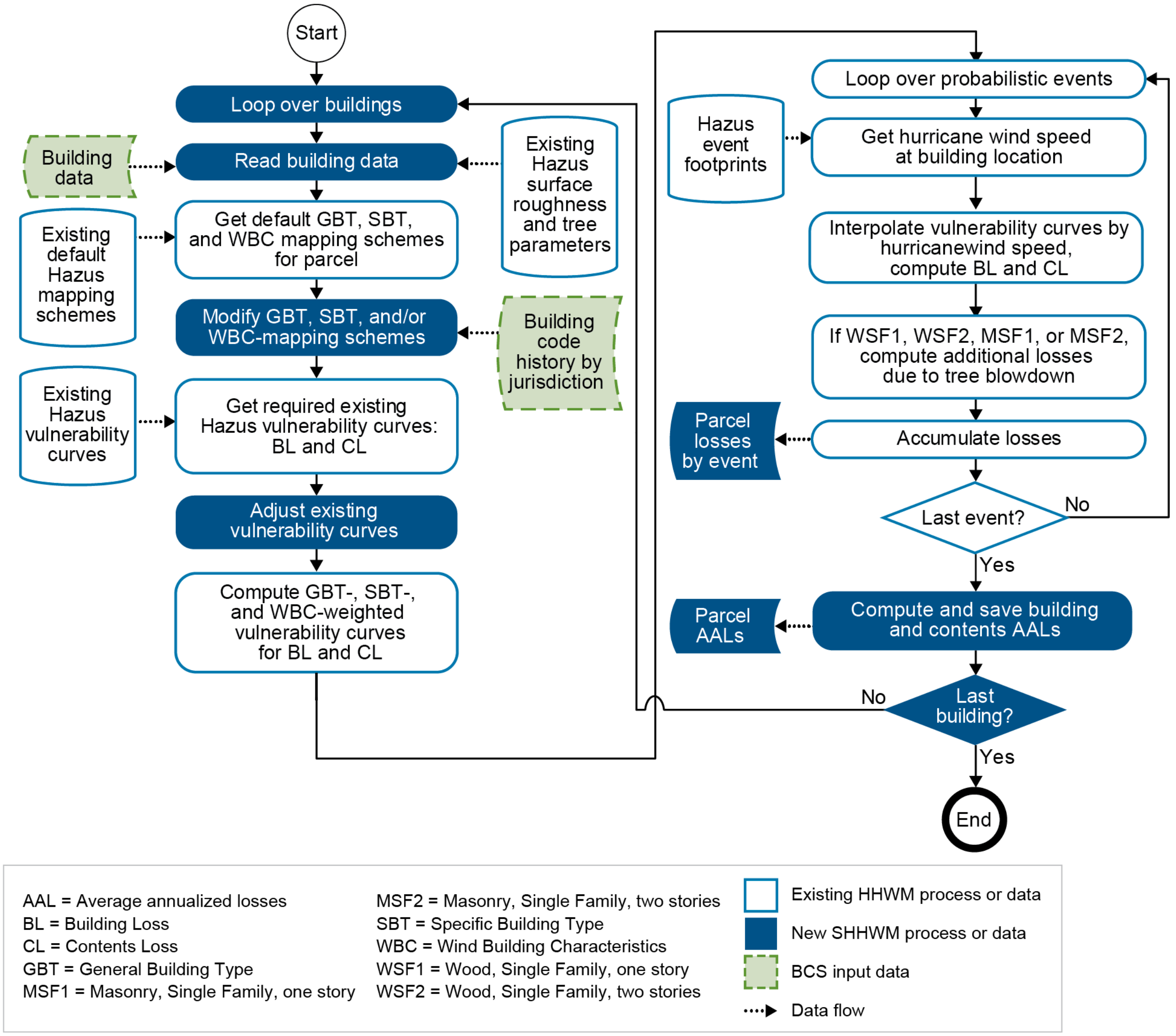
The BCEGS data provides snapshots of building code history at the jurisdiction level. Thus, for buildings located in BCEGS communities, at least some building code history was available and some of the losses avoided could be computed. The limitations of the BCEGS data are:

- It only includes a limited number of communities in each state (Alabama – 199, Georgia – 477, Texas – 532, Vermont – 14, West Virginia – 67).
- The building code history may not capture all model code adoptions since the BCEGS data are not collected often enough (approximately once every 5 years) to capture all model code adoptions.
- It does not capture amendments to the model codes made by local jurisdictions.
- The building code history provided only dates back to the year 2000 so it is not clear what building codes had been adopted prior to 2000.

E.2 Supplemental Information for Hurricane Wind Modeling Methodology

As discussed in Section 5.3, a new Stand-alone Hazus Hurricane Wind Model (SHHWM) was developed for this project to compute Average Annual Losses (AALs) and losses avoided on a building-by-building basis. Figure E-1 shows the flow of the SHHWM program. For efficiency, the SHHWM program omits all of the GIS, inventory display and editing, and output reporting features of the HHWM, and it is designed to run for one state at a time. Given a specified state, all of the databases shown in Figure E-1 are read in from the appropriate Hazus state dataset at the start of the program, and held in memory throughout program execution. After the static state datasets are read into memory, there are two main loops in the program: a loop over each post-2000 building in the state, and a loop over the hurricane event set for each building location. Prior to entering the inner loop over the hurricane event set, a mean building loss curve and a mean contents loss curve are developed for each building. The mean loss curves are weighted combinations of the approximately 5,000 existing model losses underlying Wind Building Types (WBTs) in the Hazus Hurricane Wind Model (HHWM).

The probability or weight associated with each WBT is initially set to the HHWM default. The weights are then increased to 1 for WBCs that are known to be present in a building, and decreased to 0 for characteristics that are known to be absent. Knowledge of WBCs can either come directly from the parcel-level data (e.g., construction type, number of stories, roof shape, or attached garage) or be inferred from the applicable building code requirements (e.g., hurricane straps, roof deck nailing pattern, glazed opening protection, window design pressure, or full load path design).



AAL = Average annualized losses
BL = Building Loss
CL = Contents Loss
GBT = General Building Type
MSF1 = Masonry, Single Family, one story
MSF2 = Masonry, Single Family, two stories
SBT = Specific Building Type
WBC = Wind Building Characteristics
WSF1 = Wood, Single Family, one story
WSF2 = Wood, Single Family, two stories

Figure E-1: Stand-alone Hazus Hurricane Wind Model (SHHWM) flow chart

As summarized in Figure E-2, there are from 4 to 320 WBTs in each of the 39 HHWM Specific Building Types (SBTs) (FEMA, 2012b). For example, for single-story, wood-frame, single-family dwellings (WSF1), the HHWM has 160 unique WBTs, which comprise all possible combinations of two roof shapes (hip/gable) times two secondary water resistance options (no/yes) times four roof deck attachment options times two roof-to-wall connection options (toenail/strap) times five possible combinations of garage door strength (none/weak/strong) and opening protection (no/yes). As illustrated in Figure E-3 for the WMUH1 SBT, the availability of some WBCs (e.g., built-up or single-ply membrane roof covers) is conditional on other WBCs (e.g., flat roof shape).

Wind Building Characteristic	Wood							Masonry																Concrete						Steel									MH				
	WSF1	WSF2	WSF1 (H)	WSF2 (H)	WMUH1	WMUH2	WMUH3	MSF1	MSF2	MSF1 (H)	MSF2 (H)	MMUH1	MMUH2	MMUH3	MLRM1	MLRM2	MLRI	MERBL	MERBM	MERBH	MECBL	MECBM	MECBH	CERBL	CERBM	CERBH	CECBL	CECBM	CECBH	SPMBS	SPMBM	SPMBL	SERBL	SERBM	SERBH	SECBL	SECBM	SECBH	MHPHUD	MH76HUD	MH94HUD-I	MH94HUD-II	MH94HUD-III
Roof Shape																																											
- Roof Shape I	2	2	2	2				2	2	2	2																																
- Roof Shape II					3*	3*	3*					3*	3*	3*																													
Roof Cover																																											
- Roof Cover Type (H)			2*	2*						2*	2*																																
- Roof Cover Type					2^	2^	2^					2^	2^	2^	2	2		2	2	2	2	2	2	2	2	2	2	2	2				2	2	2	2	2	2					
- Roof Cover Quality					2^	2^	2^					2^	2^	2^																													
- Secondary Water Resistance	2	2	2^	2^	2`	2`	2`	2	2	2^	2^	2`	2`	2`	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Roof Deck																																											
- Roof Deck Attach. I					2	2	2					2	2	2	2#	2#																											
- Roof Deck Attach. II	4	4			4	4	4	4	4			4	4	4	4#	4#	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
- Roof Deck Attach. III (Metal)															2`	2`	2`	2	2	2	2	2	2							2`	2`	2`	2	2	2	2	2	2					
- Roof Deck Attach. (H)			2*	2*						2*	2*																																
- Roof Deck Age															2^	2^	2													2	2	2											
Roof Frame																																											
- Roof Frame System															2*	2*																											
- Joist Spacing																2~																											
- Truss Spacing (H)			2~																																								
- Roof-Wall Conn.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2#	2#																											
Fenestrations																																											
- Window Area																		3	3	3	3	3	3	3	3	3	3	3	3				3	3	3	3	3	3					
- Shutters	2*	2*	2	2	2	2	2	2*	2*	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
- Garage I (Unshuttered Houses)	3^	3^						3^	3^																																		
- Garage II (Shuttered Houses)	2#	2#						2#	2#																																		
Other Characteristics																																											
- Wind Debris															4	4		4	4	4	4	4	4	4	4	4	4	4	4				4	4	4	4	4	4					
- Units Per Floor																2^																											
- Masonry Reinforcing								2	2			2	2	2	2	2	2																										
- Tie Downs																																							2	2	2	2	2
- Wall Construction (H)			2																																								
- Uplift Restraint (H)			2																																								
Combinations in HAZUS	160	160	200	40	128	128	128	320	320	40	40	256	256	256	352	544	12	96	96	96	96	96	96	48	48	48	48	48	48	6	6	6	96	96	96	96	96	96	4	4	4	4	4
																																							Total				4818

* branching characteristic

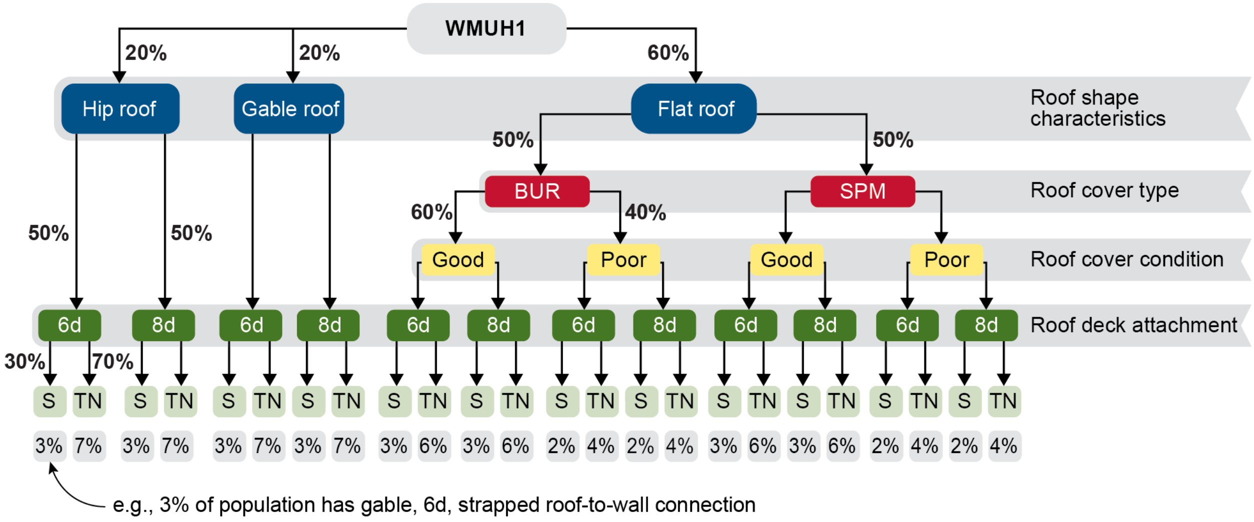
^ conditional characteristic (active if Shutters Not Installed OR if Roof Shape is Flat OR if Roof Frame System is Steel Joist OR if roof deck is superior and roof cover is shingle)

\# conditional characteristic (active if Shutters Installed or if Roof Frame System is Wood Truss)

~ conditional characteristic (active if Roof Frame System is Steel Joist and Number of Units is Multi-Unit OR if single wall and no uplift restraint)

` conditional characteristic (active if Roof Shape is Gable or Hip OR if Roof Deck is Metal and Roof Deck Age is New or Average)

Figure E-2: Wind Building Type (WBT) combinations for each HHWM Specific Building Type (SBT)



e.g., 3% of population has gable, 6d, strapped roof-to-wall connection

WMUH1 = Wood, Multi-Unit Housing, One Story
BUR = Built-up Roof
SPM = Single Ply Membrane
6d = Plywood roof deck wilh 6-penny nails at 6-inch spacing on the edges and 12-inch spacing in the field
8d = Plywood roof deck wilh 8-penny nails at 6-inch spacing on the edges and 12-inch spacing in the field
S = Strapped roof-to-wall connection
TN= Toenailed roof-to-wall connection

Figure E-3: Partial depiction of Wind Building Type (WBT) weights for the single-story, wood-frame, multi-unit housing (WMUH1) Specific Building Type (SBT). Due to space limitations, shutters, secondary water resistance, and two of the four roof deck attachment types are not shown and are effectively given zero weight in this example.

To compute the AAL for the pre-2000 International Codes (pre-I-Code) scenario, a site-specific set of WBT weights is generated by the SHHWM using the available building-level details and the pre-I-Code requirements for each building. In general, the pre-I-Code scenario is intended to represent the building code that was in effect in 1999; however, the three contiguous southeast Florida counties of Miami-Dade, Broward, and Palm Beach are an exception to this general rule. Following Hurricane Andrew in 1992, Miami-Dade and Broward Counties adopted significantly improved design requirements to the South Florida Building Code (SFBC), and the neighboring county of Palm Beach amended the SBC to require missile impact protection of glazed openings for many occupancy classes. Because the SFBC improvements formed the basis for the future Florida Building Code (FBC) High-Velocity Hurricane Zone (HVHZ), and the Palm Beach County amendments were similar in scope to future WBDR requirements, these changes are considered I-Code or similar code provisions for the purposes of this study, and were therefore not considered as being in effect for the pre-I-Code scenario. Therefore, the pre-I-Code scenario for Florida is effectively taken to be the 1997 SBC for the entire state.

A second set of WBT weights is generated by the SHHWM to reflect the I-Code or similar building codes and regulatory wind maps implemented by the local jurisdictions. These weights are based on the parcel-level details and the building code adopted in that jurisdiction as of the end of the year immediately preceding the year built. Using this second set of WBT weights, probabilistic AALs were computed for the I-Code or similar code adoption scenario. The difference between the pre-I-Code AAL and the I-Code or similar code AAL is the Average Annual Losses Avoided.

E.2.1 Building Code History Model

The building code history model considers design criteria from the *Standard Building Code* (SBC), Building Officials and Code Administration (BOCA), *National Building Code* , Council of American Building Officials (CABO), IBC/IRC, FBC, and FBCR. For single-family dwellings (RES1) and duplexes (RES3A), design criteria for opening protection (shutters), roof deck attachment, and roof-to-wall connections are included in the model. In the original Hazus model, these WBCs were all included for single-family dwellings and duplexes. However, the addition of the building code history in the SHHWM influences the results, because the requirements of pre-2000 legacy codes (SBC, BOCA, and CABO) are less stringent than those of the I-Codes.

The building code adoption dates and corresponding years built modeled for Florida are shown in Table E-1. In Table E-1, FBC(R) 2006 is an unofficial designation used herein for the FBC(R) 2004 with the following amendments:

- Ring-shank nails are required for all roof deck attachments for prescriptive designs (12/8/2006)
- Elimination of the Panhandle Exception for the WBDR (2/1/2007)
- Elimination of the partially enclosed design option (7/1/2007)

Table E-1: Florida Building Code History

Building Code	Adopted	Years Built	ASCE 7	WFCM	IBC/IRC
SBC 1997(1)	Pre-2000	2000–2002	7-95	1995	N/A
FBC 2001	3/1/2002	2003–2005	7-98	1995	N/A
FBC(R) 2004	10/1/2005	2006–2007	7-02	2001	2003
FBC(R) 2006(2)	7/1/2007	2008–2009	7-02	2001	2003
FBC(R) 2007	3/1/2009	2010–2012	7-05	2001	2006
FBC(R) 2010	3/15/2012	2013–2015	7-10	2001	2009
FBC(R) 2014	7/1/2015	2016–2018	7-10	2012	2012
FBC(R) 2017	1/1/2018	2019	7-10	2015	2015

(1) The SBC was used in Florida for years prior to adoption and enforcement of the FBC 2001, with two exceptions included for modeling: 1) Miami-Dade and Broward Counties used the SFBC; and 2) Palm Beach County used SBC with shutters on single-family dwellings and duplexes.

(2) FBC 2006 is an unofficial designation used herein for the FBC 2004 with 12/8/2006, 2/1/2007, and 7/1/2007 supplements.

WFCM = Wood-Frame Construction Material

E.2.1.1 Wind-Borne Debris Region/Shutters

WBDRs are included in the IBC and FBC, but not in the SBC, BOCA, or CABO. The evolution of the Florida WBDR is summarized in Table E-2.

Table E-2: WBDR Definitions in Florida

Building Code	ASCE Map	Year Built	WBDR	Partially Enclosed Design Option?
SBC 1997	7-93	2000–2002	N/A	N/A
FBC 2001	7-98	2003–2005	≥120 mph or ≥110 mph within 1 mile of coast(1)	Yes
FBC(R) 2004	7-98	2006–2007	≥120 mph or ≥110 mph within 1 mile of coast(1)	Yes
FBC(R) 2006	7-98	2008–2009	≥120 mph or ≥110 mph within 1 mile of coast	No
FBC(R) 2007	7-98	2010–2012	≥120 mph or ≥110 mph within 1 mile of coast	No
FBC(R) 2010	7-10	2013–2015	≥140 mph or ≥130 mph within 1 mile of coast	No
FBC(R) 2014	7-10	2016–2018	≥140 mph or ≥130 mph within 1 mile of coast	No
FBC(R) 2017	7-10	2019	≥140 mph or ≥130 mph within 1 mile of coast	No

(1) In the Florida counties of Bay, Calhoun, Escambia, Franklin, Gulf, Liberty, Okaloosa, Santa Rosa, Walton, and Washington, the WBDR was defined in the FBC 2001 and 2004 as only the area within 1 mile of the coast. This amendment, known as the Panhandle Exception, was eliminated in the July 1, 2007, supplement to the FBC 2004 (designated herein as FBC 2006).

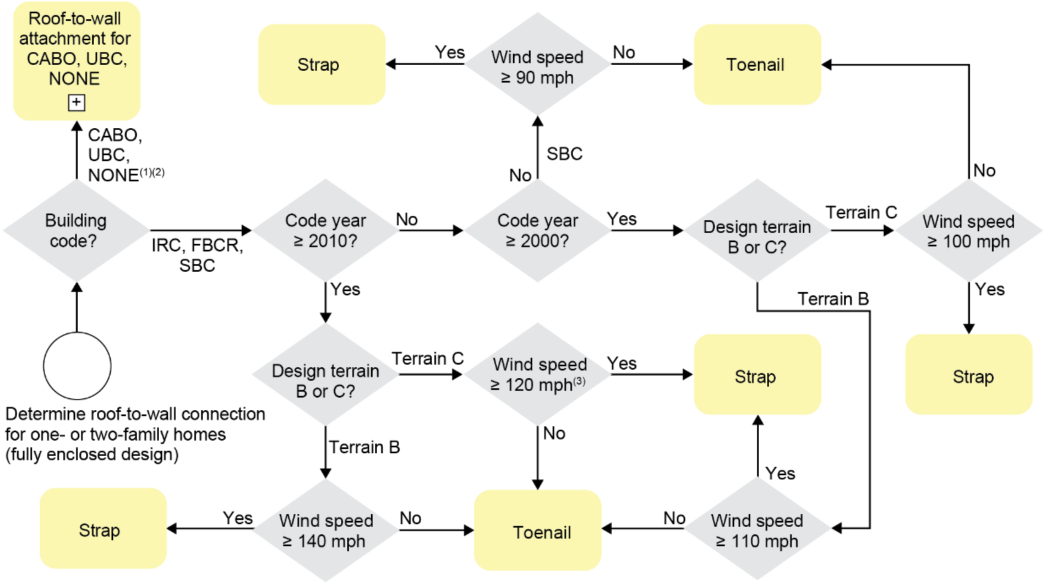
As shown in Table E-2, and discussed in the previous section, the partially enclosed design option was eliminated when the 2007 supplements to FBCR 2004 were adopted and enforced. This change, along with the elimination of the Panhandle Exception around the same time, means that all buildings with a year built of 2008 or later in the WBDR require opening protection. Prior to the requirement for shutters in the WBDR, shutters were used in:

- The HVHZ (for all versions of the FBC)
- Palm Beach County (with use of SBC from 2000 to 2002)

In the original Hazus methodology, shutters were assumed to be present in a relatively small proportion of buildings, because they were not required for most of the building stock in existence at that time. Therefore, the opening protection requirements in the SFBC, the FBC HVHZ, and the WBDR are a significant driver of hurricane wind losses avoided.

E.2.1.2 Roof-to-Wall Connection

The roof-to-wall connection is modeled based on the design terrain and wind speed determined from the applicable building code. Figure E-4 shows an example of the logic used for the fully enclosed design options of the codes in Florida. Buildings required to have opening protection,



(1) NONE indicates that no building code was adopted. In this case, Hazus default distributions are used for roof-to-wall connection.
(2) BOCA is not shown because none of the hurricane wind hazard study area states adopted BOCA for one- or two-family homes.
(3) For FBCR 2010, this wind speed is 130 mph.

Figure E-4: Roof-to-wall connection flowchart for one- and two-family dwellings with fully enclosed designs

or located outside of the WBDR, would have been designed using the enclosed design cases; whereas buildings in the WBDR (but not the HVHZ) using FBC 2001 and 2004 could be designed as partially enclosed, with no opening protection. For the partially enclosed case (FBC 2001 and 2004 in the WBDR, but not HVHZ), the design wind speed used to determine whether straps are required is either the same as or less than that shown in Figure E-4. The partially enclosed design option did not exist in the SBC. Therefore, the FBC 2001 and 2004 yield losses avoided in the WBDR.

E.2.1.3 Roof Deck Attachment

Roof deck attachments were modeled in the original Hazus methodology using the resistances in Table E-3.

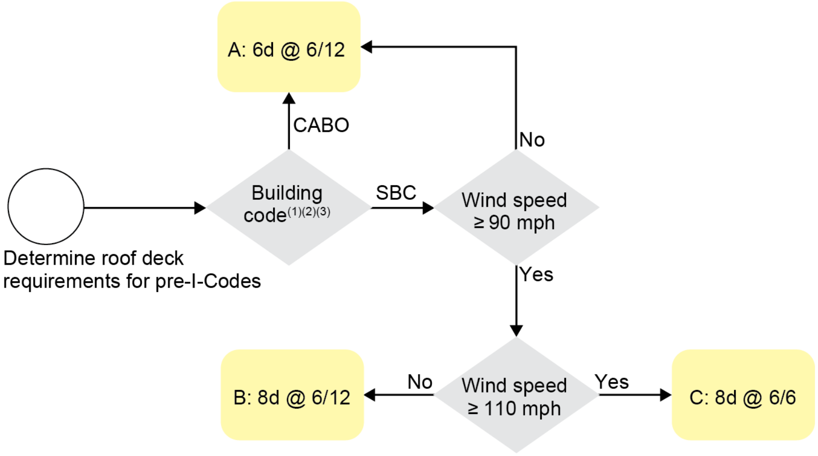
Table E-3: Existing Roof Deck Attachment Options in the HHWM

Roof Deck Attachment[1]	Mean Resistance (psf)	COV
A: 6d @ 6 inch / 12 inch	54.6	0.11
B: 8d @ 6 inch / 12 inch	103.3	0.11
C: 8d @ 6 inch / 6 inch	181.9	0.11

(1) There is also a fourth roof deck attachment option for a mixture of 6d and 8d nails at 6-inch/6-inch spacing. This roof deck attachment was included in Hazus to permit modeling of roof decks that originally had 6d @ 6-inch/12-inch attachments, and were later retrofit with 8d nails added between the 6d @ 12-inch nails. This fourth option was not used in the current study.

COV = coefficient of variation

The building code requirements were incorporated into the Hazus methodology to select the appropriate roof deck attachment from Table E-3. For example, the logic used to select the roof deck attachments for pre-I-Code designs is shown in Figure E-5. Section E.2.2.1 discusses the use of ring-shank nails in Florida for roof deck attachments.



(1) BOCA is not shown because none of the hurricane wind hazard study area states adopted BOCA for one- or two-family homes.
(2) UBC is not shown because Hazus uses standard and superior roof deck attachment categories for Hawaii instead of the three categories shown here.
(3) NONE is not shown because it indicates that no building code is adopted. In this case, Hazus default distributions are used for roof deck attachment based on region.

Figure E-5: Roof deck attachment flowchart for pre-I-Code one- and two-family dwellings

E.2.1.4 Full Load Path for Wood Construction

A limitation of the original Hazus methodology was that the wood-frame wall failure model only considered flexural failure due to out-of-plane loads. The methodology has since been updated to include modeling of the top-plate-to-stud connection, bottom-plate-to-stud connection, and bottom-plate-to-foundation connection. All of the building codes that were reviewed include some language that requires the load to be transferred from the roof to the wall, and down to the foundation. Figure E-6 shows an example of the logic that was used to select the top- and bottom-plate-to-stud connections for FBCR 2004.

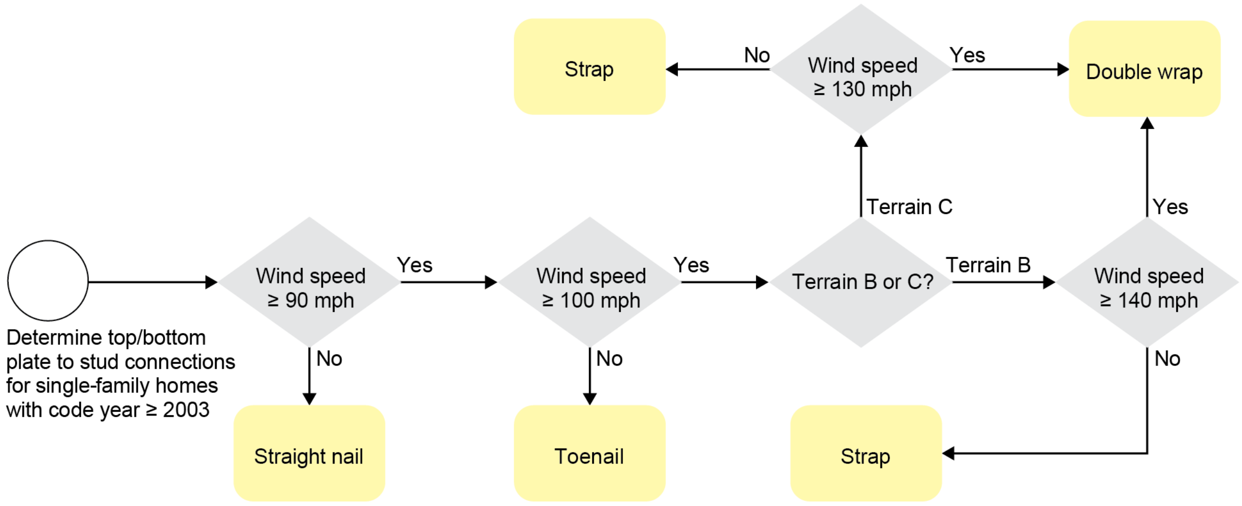


Figure E-6: Top- and bottom-plate-to-stud connection flowchart for FBCR 2004 (enclosed design)

E.2.1.5 Window Design Pressures

Another improvement that has been made to the Hazus methodology is the determination of design window pressures for engineered buildings. In the original Hazus methodology, all windows on engineered buildings were modeled as having a mean failure pressure of 75 psf with a coefficient of variation of 20%. This corresponds to a design pressure (5% failure rate) of approximately 50 psf.

In the updated methodology, the building codes are used to determine appropriate window design pressures. Figure E-7 and Figure E-8 show the logic used to determine the appropriate window design pressure for low- and high-rise buildings[5] for FBC 2010. Figure E-7 shows that this improvement in methodology can make the windows stronger, weaker, or the same as the original Hazus methodology for low-rise engineered buildings using FBC 2010 or later. Figure E-8 shows that engineered high-rise buildings designed using FBC 2010 or later will have stronger windows than the original Hazus methodology.

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[5] low-rise = less than or equal to 60 feet (i.e., the two- and five-story model buildings); high-rise = more than 60 feet (i.e., the eight-story model buildings)

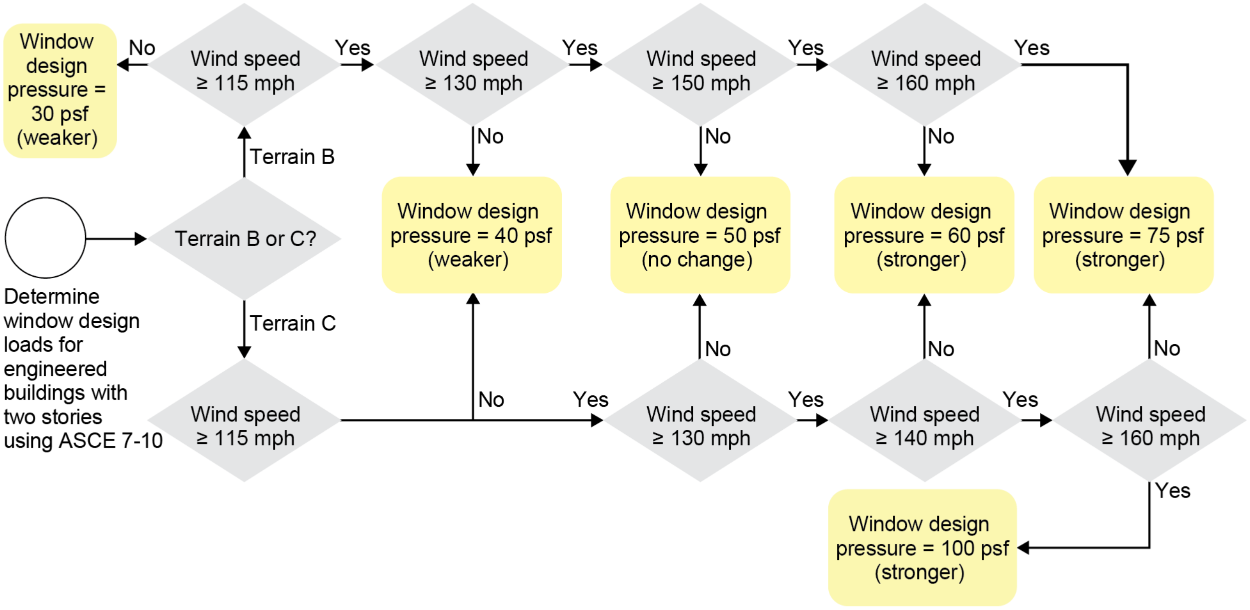


Figure E-7: Logic for design window pressures of low-rise engineered buildings for FBC 2010 and later editions

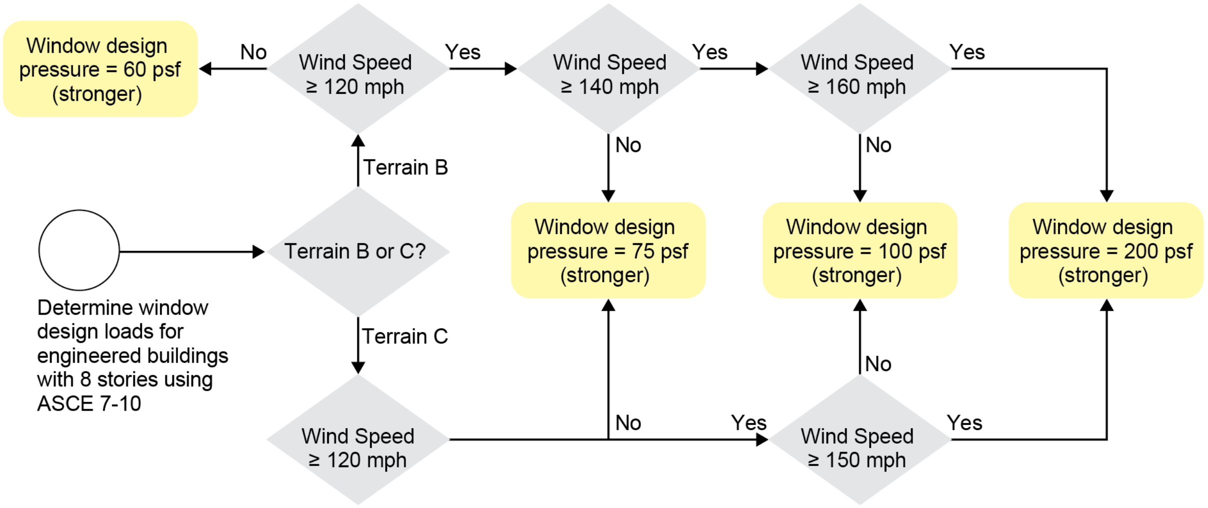


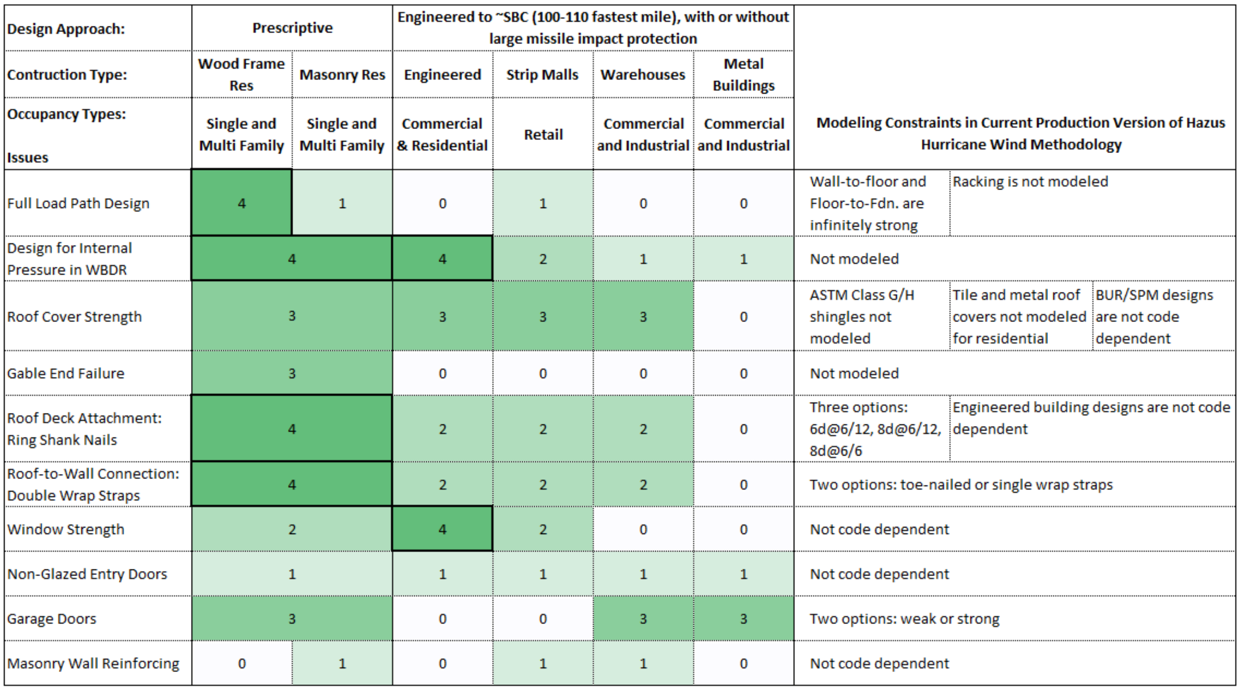
Figure E-8: Logic for design window pressures in high-rise engineered buildings for FBC 2010 and later editions

E.2.2 Hazus Loss Modification Functions

To better reflect the effects of recent building code improvements, a set of loss modification functions (LMFs) was developed to extend the applicability of the existing HHWM loss functions. Table E-4 summarizes the range of enhancements considered for this study. Due to resource limitations, it was only possible to explicitly model the six highest-priority enhancements (denoted by "4" in Table E-4) that were expected—based on the judgment of the

BCS project team and limited input from outside reviewers—to have the greatest impact on losses avoided.

Table E-4: Judgment-based prioritization of potential hurricane wind loss modeling enhancements (4=highest priority, …, 1=lowest priority, 0=not applicable)



Design Approach:	Prescriptive		Engineered to ~SBC (100-110 fastest mile), with or without large missile impact protection				Modeling Constraints in Current Production Version of Hazus Hurricane Wind Methodology		
Contruction Type:	Wood Frame Res	Masonry Res	Engineered	Strip Malls	Warehouses	Metal Buildings			
Occupancy Types: Issues	Single and Multi Family	Single and Multi Family	Commercial & Residential	Retail	Commercial and Industrial	Commercial and Industrial			
Full Load Path Design	4	1	0	1	0	0	Wall-to-floor and Floor-to-Fdn. are infinitely strong	Racking is not modeled	
Design for Internal Pressure in WBDR	4		4	2	1	1	Not modeled		
Roof Cover Strength	3		3	3	3	0	ASTM Class G/H shingles not modeled	Tile and metal roof covers not modeled for residential	BUR/SPM designs are not code dependent
Gable End Failure	3		0	0	0	0	Not modeled		
Roof Deck Attachment: Ring Shank Nails	4		2	2	2	0	Three options: 6d@6/12, 8d@6/12, 8d@6/6	Engineered building designs are not code dependent	
Roof-to-Wall Connection: Double Wrap Straps	4		2	2	2	0	Two options: toe-nailed or single wrap straps		
Window Strength	2		4	2	0	0	Not code dependent		
Non-Glazed Entry Doors	1		1	1	1	1	Not code dependent		
Garage Doors	3		0	0	3	3	Two options: weak or strong		
Masonry Wall Reinforcing	0	1	0	1	1	0	Not code dependent		

Details on the development of the LMFs for full load path design for wood-frame construction, enhanced roof deck attachment requirements for plywood or oriented strand board (OSB) roof sheathing in Florida using ring-shank nails, and building-code-dependent window designs for engineered steel or reinforced-concrete-framed buildings are described in the subsections below.

E.2.2.1 Ring-Shank Nails

Ring-shank nails were not required for roof deck attachments by any building code prior to the FBCR 2004. The FBC 2004 requires ring-shank nails in the HVHZ only. A supplement to the FBCR 2004 required ring-shank nails to be used for all single-family dwellings in Florida (Figure E-9). However, for multi-family dwellings, ring-shank nails continue to be required only in the HVHZ (Figure E-10).

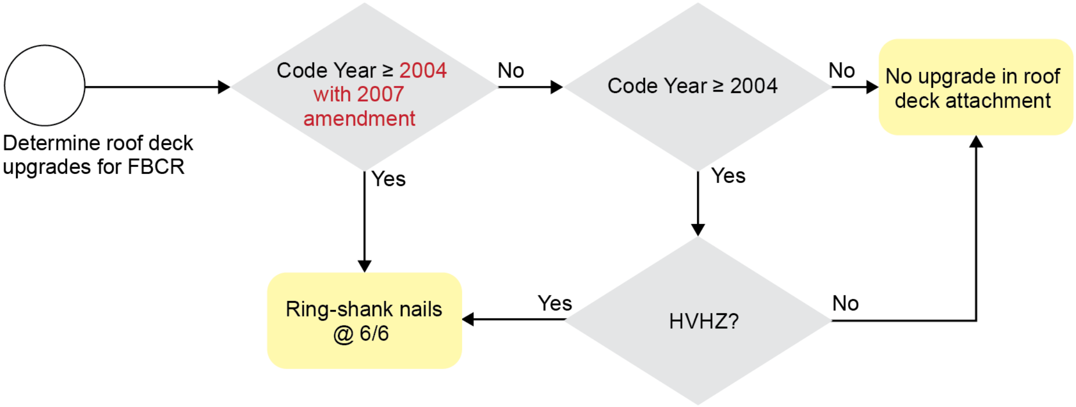


Figure E-9: Flowchart showing ring-shank nail requirements for one- and two-family dwellings in Florida

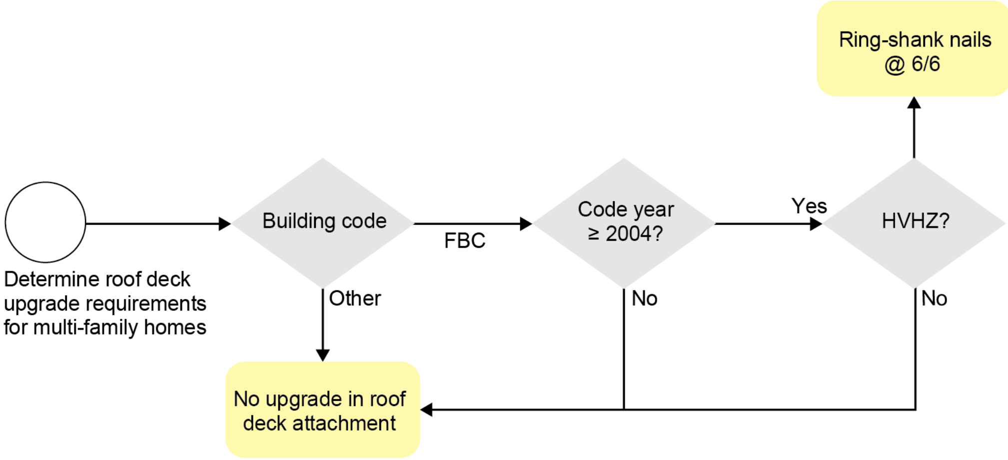


Figure E-10: Flowchart showing ring-shank nail requirements for multi-family dwellings in Florida

LMFs were developed by completing additional runs after modifying the Hazus methodology to include ring-shank nails and normalizing the losses produced by those runs to those for the next strongest roof deck attachment (8d @ 6 inches / 6 inches).

Table E-5 shows the loss modification runs that were completed for ring-shank nail roof deck attachments. All of these cases were for strong houses (as defined in Table E-5), including those with opening protection and double-wrap roof-to-wall connections. The figures in the last row represent the number of cases modeled for each building feature, with the product shown in the last column.

Table E-5: Loss Modification Cases for Ring-Shank Nails

Feature Variations / Modeled Cases	**Building Feature**							**Total Modeled Cases**
	Stories	Roof Shape	SWR	Roof Deck Attachment(1)	Roof-to-Wall Connection	Garage Door/ Shutters	Terrain(1)	
Feature variations	• 1 • 2	• Gable • Hip	• Yes • No	• Ring-shank	• Double wraps • Single strap	• 40 psf/Yes • No garage/Yes	• 1 • 2 • 3 • 4 • 5	
No. modeled cases	2	2	2	1	2	2	5	160(2)

SWR = secondary water resistance

(1) Terrain definitions:
1 = open terrain (z_0=0.03 m)
2 = light suburban terrain (z_0=0.15 m)
3 = suburban terrain (z_0=0.35 m)
4 = treed terrain (z_0=0.70 m)
5 = urban terrain (z_0=1.00 m)

(2) The total number of modeled cases is the total number of possible combinations of the building feature variations (2 x 2 x 2 x 1 x 2 x 2 x 5 = 160).

A mean uplift resistance of 396.6 psf was used to model the ring-shank nailing in the damage simulation methodology. This value is based on laboratory testing of ring-shank nails by Sutt (1996). Surprisingly, ring-shank nails provided negligible reductions in building and contents losses. As a result, this code improvement is only a minor contributor to the modeled losses avoided in Florida. Figure E-11 and Figure E-12 show that the roof deck connections of both 8d @ 6-inch/6-inch and ring-shank nails contribute very little to the damage of buildings below a wind speed of 200 mph because other WBCs (e.g., windows, roof cover) fail first. Lines are not shown on these figures for the WBCs that produce no damage (e.g., whole roof and ring-shank nails). As a result of this finding, the run cases were not expanded to include weaker houses, because ring-shank nails would have even less impact.

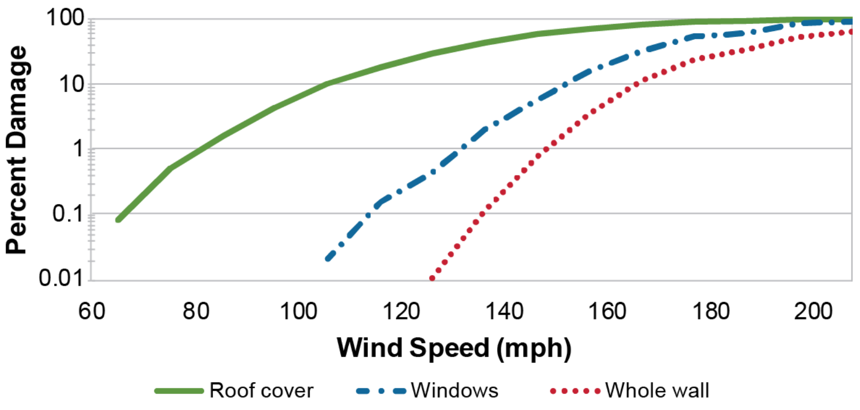


Figure E-11: Example building damage for strong two-story dwelling with hip roof, secondary water resistance, ring-shank nail roof deck attachment, double wraps, no garage, and shutters

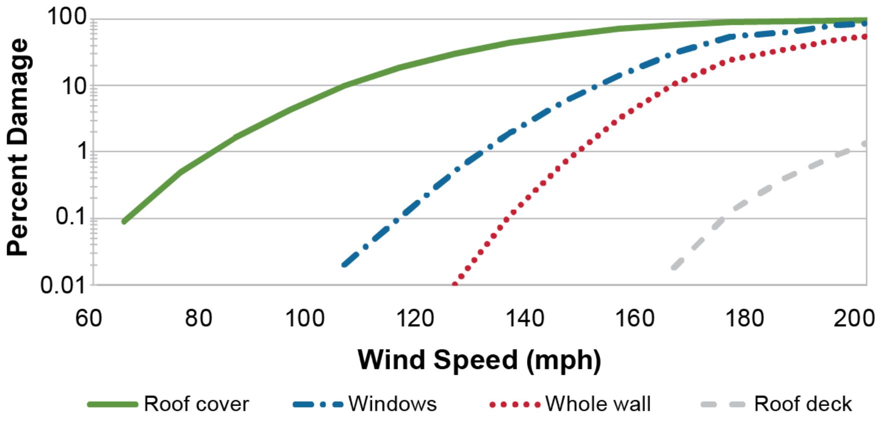


Figure E-12: Example building damage for strong two-story dwelling with hip roof, secondary water resistance, 8d @ 6 inch/6 inch roof deck attachment, double wraps, no garage, and shutters

E.2.2.2 Full Load Path

As discussed in Section E.2.1.4, the Hazus methodology was improved by incorporating the ability to model a full load path (FLP) from the roof to the foundation. Specifically, the bottom- and top-plate-to-stud connection and bottom-plate-to-foundation connection are included in the updated model. The bottom- and top-plate connections are modeled as either straight nails, toenails, straps, or double wraps. Table E-6 shows the runs that were completed to develop LMFs for the full load path. For each case, the bottom-plate-to-foundation connection was assumed to be bolted. The figures in the last row represent the number of cases modeled for each building feature, with the product shown in the last column.

Table E-6: Full-Load-Path Cases for Wood-Frame Single-Family Homes

Feature Variations / Modeled Cases	Building Feature								**Total Modeled Cases**
	Stories	Roof Shape	SWR	Roof Deck Attachment[1]	Roof-to-Wall Connection	Garage Door/ Shutters	Terrain[2]	Foundation Conn, Top and Bottom Plate	
Feature variations	• 1 • 2	• Gable • Hip	• No • Yes	• 6d • 8d • 6s • 8s	• Toenail • Single wrap	• No garage/No • No garage/Yes • 10 psf/No • 20 psf/No • 40 psf/Yes	• 1 • 2 • 3 • 4 • 5	• Toenail • Straight nail • Strap • Double wrap	
No. modeled cases	2	2	2	4	2	5	5	4	6,400[3]

SWR = secondary water resistance

(1) Roof deck attachment definitions:
6d = 6d nails at 6-inch spacing on the edges and 12-inch spacing in the field
8d = 8d nails at 6-inch/12-inch spacing
6s = 6d nails at 6-inch/12-inch spacing with 8d nails at 12-inch spacing added in the field
8s = 8d nails at 6-inch/6-inch spacing

(2) Terrain definitions:
1 = open terrain (z_0=0.03 m)
2 = light suburban terrain (z_0=0.15 m)
3 = suburban terrain (z_0=0.35 m)
4 = treed terrain (z_0=0.70 m)
5 = urban terrain (z_0=1.00 m)

(3) The total number of modeled cases is the total number of possible combinations of the building feature variations (2 x 2 x 2 x 4 x 2 x 5 x 5 x 4 = 6,400).

Figure E-13 and Figure E-14 show that by incorporating the full load path requirements into the Hazus model, the losses will increase slightly. These figures also show that, like ring-shank nails, full load path requirements are not a big contributor to losses avoided in Florida. Nonetheless, ring-shank nails and full load paths are inexpensive improvements that will reduce the number of catastrophic failures in extreme events provided that the rest of the structure is well-engineered and well-constructed.

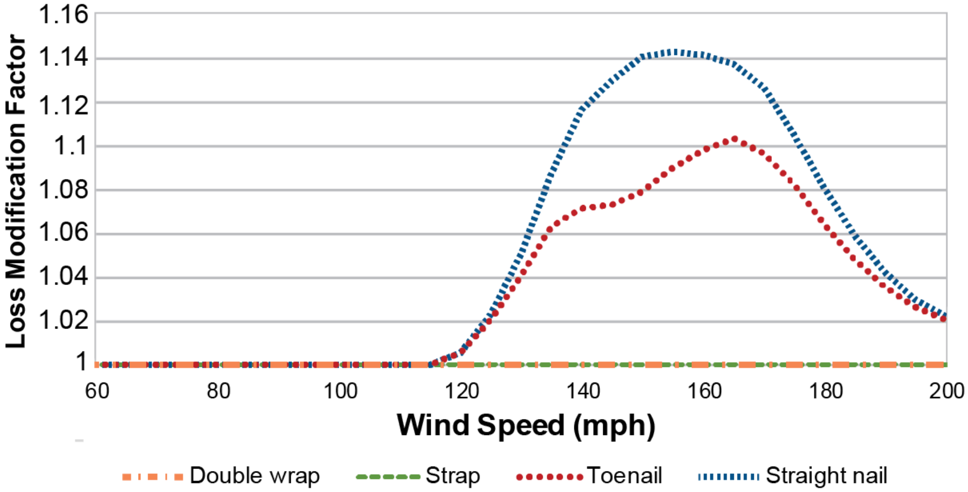


Figure E-13: Example loss modification functions for full load path (FLP) of wood-frame single-family dwelling, one story, gable roof, no secondary water resistance, 8d @ 6-inch/12-inch, strapped roof-to-wall connection, standard garage door, no shutters, Terrain 3

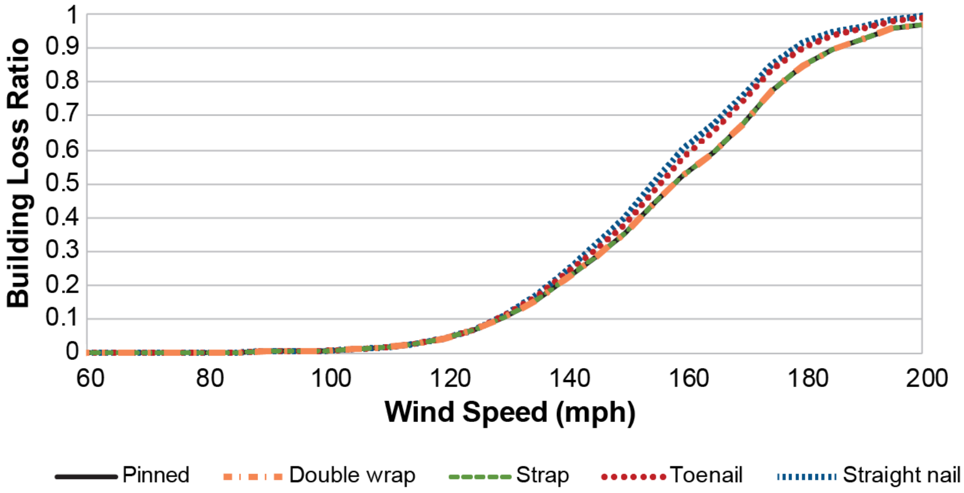


Figure E-14: Example loss functions for full load path in a wood frame single-family dwelling, one story, gable roof, no secondary water resistance, 8d @ 6-inch/12-inch, strapped roof-to-wall connection, standard garage door, no shutters, Terrain 3

E.2.2.3 Window Design Pressures

As discussed in Section E.2.1.5, the window design pressures based on the building code history are new to the Hazus methodology. LMFs for window design pressures were developed for engineered buildings only. For engineered buildings, LMFs were developed for the cases summarized in Table E-7. In the original Hazus methodology, the mean window pressure was set to 75 psf for all engineered buildings. For these runs, we determined the impact of changing the window design pressure based on design calculations using building codes. We modified the original methodology used for Hazus so that the window design pressure would be entered as a 5th percentile rather than 50th. Therefore, 50 psf is not shown in the tables below because it corresponds to a mean of 75 psf (i.e., the window resistance pressure in the original Hazus methodology).

The cases for which we provide LMFs for concrete engineered buildings are shown in Table E-7. The figures in the last row represent the number of cases modeled for each building feature, with the product shown in the last column.

Table E-7: Window Design Pressure Cases for Reinforced Concrete Frame Engineered Buildings

Feature Variations / Modeled Cases	**Building Feature**								**Total**
	Type	Stories	Roof Cover	Glazing(1)	Opening Protection	Missile Environment(3)	Window Design Press (psf)	Terrain(2)	
Feature variations	• Residential • Commercial	• 2 • 5 • 8	• BUR • SPM	• 20% (L) • 33% (M) • 50% (H)	• No • Yes	• A • B • C • D	• 20 • 30 • 40 • 60 • 75 • 100 • 200	• 1 • 2 • 3 • 4 • 5	
No. modeled cases	2	3	2	3	2	4	7	5	10,080(4)

BUR = built-up roof

SPM = single-ply membrane

(1) Glazing definitions:
20% (Low)
33% (Medium)
50% (High)

(2) Terrain definitions:
1 = open terrain (z_0=0.03 m)
2 = light suburban terrain (z_0=0.15 m)
3 = suburban terrain (z_0=0.35 m)
4 = treed terrain (z_0=0.70 m)
5 = urban terrain (z_0=1.00 m)

(3) Missile environment definitions:
A = Mixture or residential and commercial building debris from all eight wind direction sectors
B = Residential building debris from six of eight sectors and commercial building debris from two sectors
C = Residential building debris from all eight wind direction sectors
D = None

(4) The total number of modeled cases is the total number of possible combinations of the building feature variations (2 x 3 x 2 x 3 x 2 x 4 x 7 x 5 = 10,080).

The cases in Table E-7 were repeated for the Hazus steel-frame engineered buildings with a roof deck designed to withstand a fastest mile wind speed of 100 mph. Due to resource limitations and the very large number of cases involved, the same LMFs were used for the 110 mph roof deck design case.

Once all the runs were completed, LMFs were generated for each of the engineered buildings with the same WBCs, and then normalized relative to the loss function produced using the original Hazus methodology (Figure E-15). Buildings with stronger window design pressures than used in the original Hazus methodology produce loss adjustment factors of less than 1, whereas windows with weaker design pressures than the original Hazus methodology produce loss adjustment factors of greater than 1. In the updated Hazus methodology, the loss functions from the original Hazus methodology are multiplied by these LMFs to produce modified loss functions. Figure E-16 shows example LMFs for an engineered mid-rise concrete building. These figures demonstrate that the window design pressures from building codes can have a significant impact on the losses of a building, particularly for an engineered concrete building, because the windows are the main WBC that experiences damage.

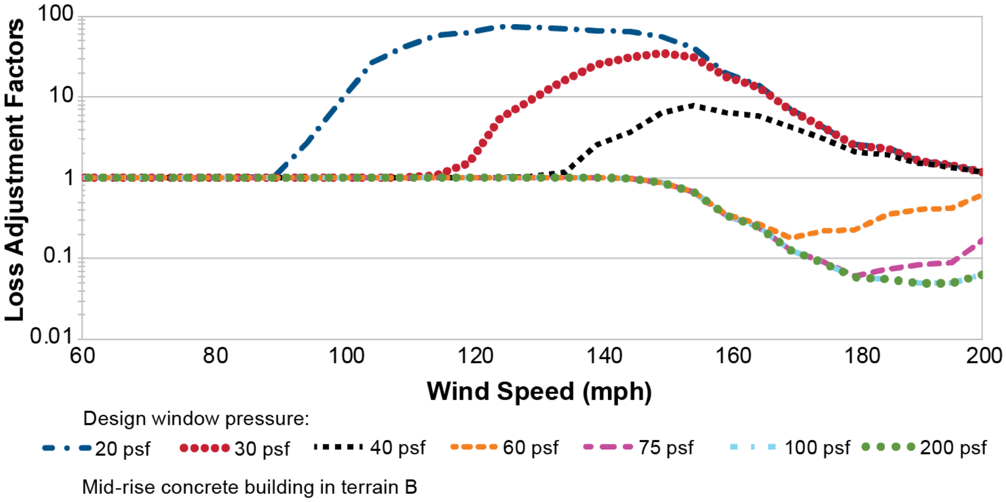


Figure E-15: Example loss modification functions for engineered mid-rise concrete building in Terrain 3

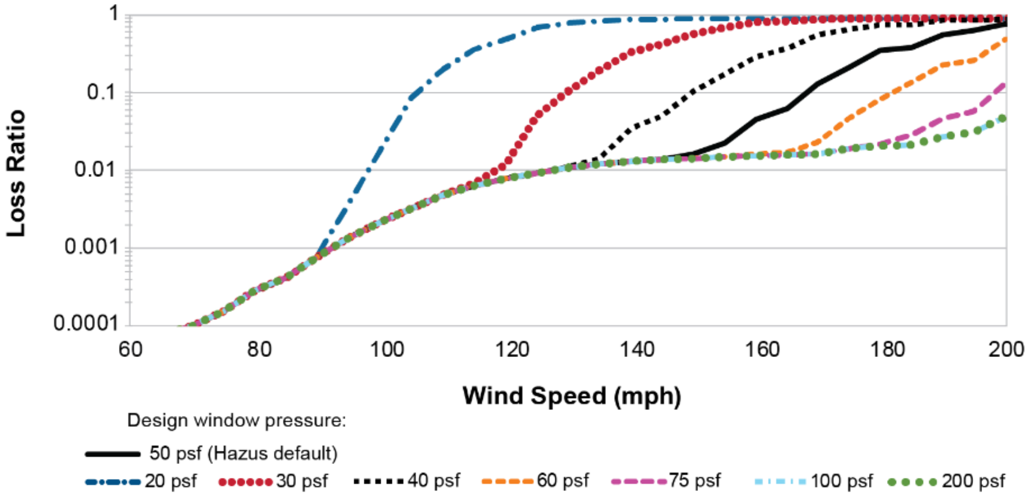


Figure E-16: Example loss functions for engineered mid-rise concrete building with different window design pressures in Terrain 3

APPENDIX F:
Seismic Hazard Methodology Details

F.1 Supplemental Code Adoption History

F.1.1 Identification of the Pre-IBC Code

The seismic provisions in the 2000 *International Building Code*® (IBC®) are essentially the same as those in the 1997 National Earthquake Hazards Reduction Program (NEHRP) *Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (FEMA, 1997). The seismic provisions of the 1997 *Uniform Building Code* (UBC) (ICBO, 1997) and the 1997 NEHRP Provisions were developed during the same period and, in many cases, by the same people, who were members of both the Structural Engineers Association of California (SEAOC) Seismology Committee and the Building Seismic Safety Council's NEHRP Provisions Update Committee (PUC). Accordingly, the seismic provisions of the 1997 UBC and the 2000 IBC produce seismic designs of similar strength.

The SEAOC Seismology Committee that developed the seismic provisions of the UBC was constrained somewhat by the historical use of seismic zones to specify hazard, and also by a design specification format, whereas the NEHRP Provisions were considered more of a resource document for future codes. The NEHRP PUC was, therefore, less constrained. Both groups knew that designs resulting from their provisions would be compared, and that variations could create a lack of credibility.

Regions in California near well-known active faults were known to experience ground motions more severe than projected for traditional UBC Zone 4; SEAOC chose to maintain the UBC zone format, but to overlay more severe hazard near those faults, called near-fault factors. Outside California, the pure zone format was maintained.

The PUC, on the other hand, felt more comfortable adopting maps of contours of ground accelerations, developed by the U.S. Geological Survey (USGS), eliminating the need for zones. In California, the contoured maps of acceleration were not unlike the UBC zones plus the near-fault factors; so in general, the design hazard is very similar.

In addition, there were minor differences in R factors for some structural systems (R factors control the amplitude of the design lateral force). The differences were applicable only to a few structures, and were limited to a 10% or less effect on the building strength. These differences do not justify a change in the assignment of Hazus Design Levels.

Therefore, for the purposes of this study, the 1997 UBC was judged to be similar to the International Codes (I-Codes)—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, is the pre-I-Code code that was compared to the codes in place at the time of construction.

F.1.2 Code History in California

Commercial. Because the Structural Engineers Association of California was the primary author of the Blue Book, which served as the source for the seismic provisions of the UBC, the UBC was used throughout California for decades before the IBC was developed. In 1998, California mandated that the state code, Title 24, would apply to all occupancies in the state, and until 2008, was based on the latest edition of the UBC. The code in place in 2000 was the 1997 UBC, and as explained in Section F.1.1, the 1997 UBC is considered equivalent to the 2000 IBC. The preceding code was the 1994 UBC, which has been used as the pre-I-Code code to be compared with the 1997 UBC and/or the IBC (I-Code or similar code). The IBC was first enforced in California in 2008. California commercial code history since 1999 is detailed in Table 6-3.

Residential. As indicated in Section 6.1.2, prior to adoption of the International Residential Code (IRC), residential construction was fully engineered or constructed in accordance with prescriptive provisions of conventional construction of the UBC. Prior to the IRC, California Building Officials (CALBO) had also developed stand-alone provisions specific to residential construction that were used by some jurisdictions. These provisions are considered seismically equivalent to conventional construction, and were set equal to the use of the 1997 UBC for this study. California residential code history is detailed in Table 6-4

F.1.3 Code History in Oregon

Commercial. Oregon has adopted statewide codes based on the UBC since 1974. In October 2004, the base code was switched from the 1997 UBC to the 2003 IBC. Oregon commercial code history is detailed in Table 6-3.

Residential. The Council of American Building Officials' (CABO's) provisions in the CABO One- and Two-Family Dwelling Code (CABO, 1998) were used in Oregon prior to the IRC. Like the CALBO provisions in California, these provisions were set equal to use of the 1997 UBC for this study. The residential base code switched from CABO to the 2000 IRC in 2003. Oregon residential code history is detailed in Table 6-4.

F.1.4 Code History in Washington

Washington's code history is similar to that of Oregon and California. Washington switched from the 1997 UBC to the 2003 I-Codes in 2004. Washington's commercial and residential code histories are shown in Table 6-3 and Table 6-4.

F.1.5 Code History in Utah

According to the Utah Seismic Safety Commission, the UBC was adopted statewide in 1987 under the contractor's licensing board. This study assumed that use of the 1994 UBC and 1997 UBC was prevalent, at least in the major population centers, prior to the adoption of the IBC. The conversion to the IBC in 2002, as is documented in Salt Lake City and other cities (e.g., Pleasant View), has been assumed statewide. In 2002, the 2000 IBC was assumed for commercial buildings, and the IRC for residential buildings. IBC 2003 was adopted and mandated statewide in 2004. Commercial and residential code histories are detailed in Table 6-3 and Table 6-4. IBC 2003 was adopted and mandated statewide in 2004.

F.1.6 Code History in Alaska

Alaska suffered a large earthquake in 1964 that mostly affected Anchorage, and encouraged adoption of building codes in that area. News reports after the Magnitude 7.0 Anchorage earthquake in November 2018 credited the use of seismic building codes with minimizing the damage. The State of Alaska, therefore, has a long history of adopting commercial building codes, but there has been no statewide adoption of the IRC.

Code history information has been assembled for at least one city in each of the boroughs with CoreLogic building data, including the cities of Fairbanks (Fairbanks North Star Borough), Kenai (Kenai Peninsula Borough), Ketchikan (Ketchikan Gateway Borough), Palmer (Matanuska-Susitna Borough), and the city/boroughs of Anchorage and Juneau. Collected information was supplemented with available Building Code Effectiveness Grading Schedule (BCEGS) data. The BCEGS data document the reviews conducted by the Insurance Services Office (ISO), typically on a 5-year cycle (see Section 3.1.2); data for Alaska communities that include a pre-2000 review are only available for 1998 and 2005, typically transitioning from a UBC-based code to an IBC-based code in that time period. Engineers working in the larger cities indicate that the 1994 UBC, the 1997 UBC, or an edition of the IBC has been used by the cities since 2000.

Based on conversations with local engineers, some construction in Alaska post-2000 used antiquated codes or no codes at all; for example, the cities of Homer, Saxman, Houston, and Wasilla have no city building code, relying on the state code for commercial buildings, with no code applicable for residential structures. Further, homeowners or developers building residences outside major municipalities' inspection zones, such as Anchorage's Building Safety Service Area, are required by lending institutions providing equity to the project to adhere to the IRC. However, the inspection of such residences is usually not by independent agents; rather, the inspectors are hired by the homeowners or developers. Homeowners or developers in these places that build without the use of borrowed funds are essentially free to build whatever they wish. Accordingly, for each city known to have a building code in place, their code adoption history (or the history of the largest city in their borough) has been applied. For cities with no building code, and outside incorporated city boundaries (and outside Anchorage's Building Safety Service Area), the state's commercial code adoption history was applied, and residential structures have been assumed to have been built without the benefit of a building code. Enforcement and/or inspection, particularly before 2010, was probably inconsistent, but data sufficient to modify Hazus functions to reflect enforcement practices were not available for Alaska, or for anywhere else in the areas under study.

The commercial code history used for this study for cities and boroughs with CoreLogic building data is detailed in Table 6-3. Although some data can be found regarding use of the IBC for commercial structures in Alaska, adoption and use of the IRC, particularly before 2010, is less clear. As noted above, there has never been a statewide adoption of the IRC in Alaska. However, conventional construction practices were well founded in the UBC prior to release of the IRC. The residential code history used for this study for Alaska's cities and boroughs with CoreLogic building data is detailed in Table 6-4.

F.1.7 Code History in Hawaii

Commercial. Seismic code adoption in Hawaii has been far less systematic than in California, Oregon, Washington, and Utah. The building code adoption history in Hawaii varies by county, at least until 2008, when a statewide code was adopted (although the counties had 2 years to adopt). As shown in Table 6-3, by the late 1990s, all of the larger island-counties had caught up to the 1997 UBC, except Hawaii County, which continued to use an older edition of the UBC until the statewide code (2006 IBC) was adopted in 2008.

Residential. The history of residential code adoption in the various counties and cities of Hawaii is inconsistent and difficult to identify. Small residential construction on the island of Hawaii and Maui often uses a post and pier foundation, where the first floor is typically elevated 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-frame buildings on slab foundations. After 2000, code-required improvements to continuous load paths made these structures more resistant to damage (see Section F.3.2.3 for additional information on modeling of post and pier construction).

Since 1969, a licensed design professional has been required for essentially all buildings (Hawaii statute 464-13). Therefore, the Hazus Design Level modeling for conventional construction under the UBC (see Sections F.3.1.6 and F.3.1.7) and the prescriptive requirements of the IRC (Section F.3.1.8) are not applied for Hawaii in this study. The residential code history for Hawaii's counties is provided in Table 6-4.

F.2 Supplemental Seismic Hazard Data

A variety of seismic hazard data was required for the study: probabilistic ground motion data, soils data used in both the Design Level determination and implementation of the Hazus loss assessment, UBC Seismic Zone maps and near-fault zone maps, and county-level maps generated to prioritize the full Hazus AAL analysis effort.

F.2.1 Probabilistic Ground Motion Data

Probabilistic ground motion data derived from the USGS National Seismic Hazard Maps (NSHMs) (Petersen et al., 2014) for eight return periods (100, 250, 500, 750, 1000, 1500, 2000, and 2500 years) are incorporated into the Hazus default data sets for use in estimating AALs (FEMA, 2012c). The 2500-year return period peak ground accelerations are shown in Figure F-1.

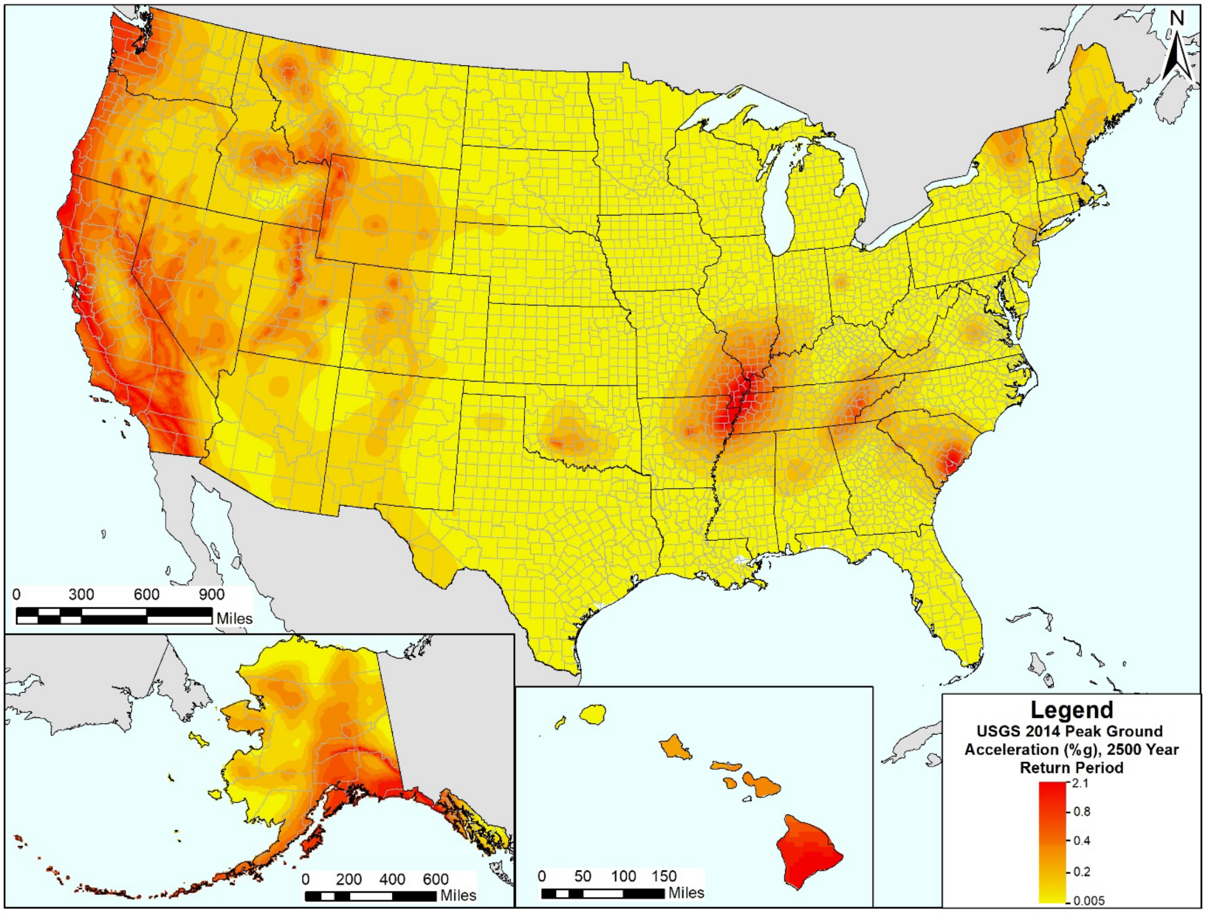


Figure F-1: Peak ground accelerations with a 2500-year return period, as derived from the 2014 USGS National Seismic Hazard Maps as stored in Hazus

F.2.2 Soils Data

Soils data required for both the Design Level determination and loss analyses in Hazus were developed for this study at the census tract level. The USGS has developed worldwide data related to the average shear wave velocity in the top 30 meters of soil (Vs30) using topographic slope as a proxy. Data for various map areas are available from the USGS website (https://earthquake.usgs.gov/data/vs30/). Relevant data were downloaded and used to create map layers in ArcGIS. To determine soil conditions in terms of NEHRP site class (see Table F-1) for individual census tracts, a Geographic Information System (GIS) database of census tract centroids was developed from the Hazus baseline data. For each census tract centroid, Vs30 data for the closest USGS grid point were used to represent the soil conditions for the tract. Census tract soils maps for the six western seismic states are shown in Figure F-2.

Table F-1: NEHRP Site Classes

Site Class	Description	Shear Wave Velocity Range (m/sec)
A	Hard rock (eastern United States sites only)	>1500
B	Rock	760 – 1500
C	Very dense soil and soft rock	360 – 760
D	Stiff soil	180 – 360
E	Soft soils	<180

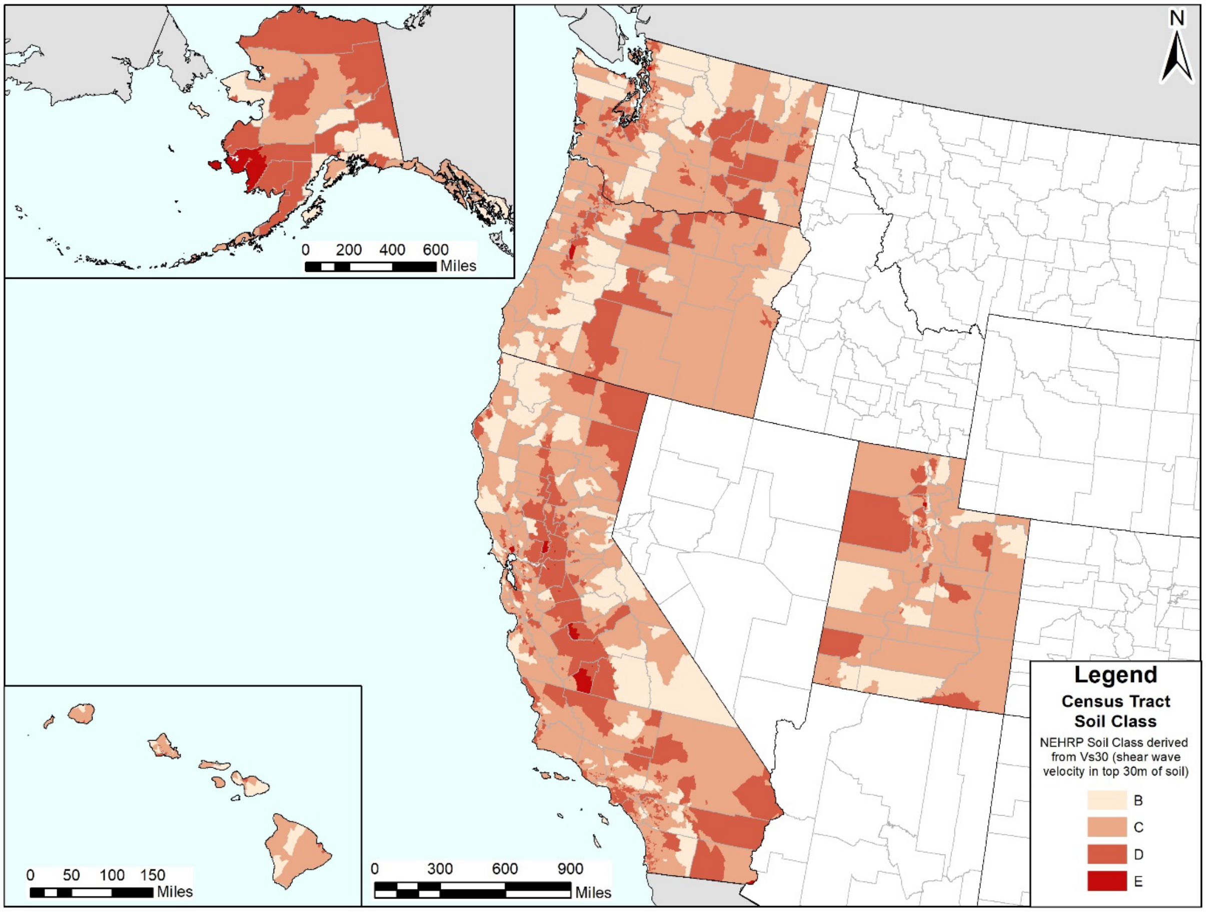


Figure F-2: NEHRP soil class by census tract for the six western seismic states (derived from USGS Vs30 grid data)

F.2.3 UBC Seismic Zone Maps and Near-Fault Data

Maps of 1994 and 1997 UBC Seismic Zones were required to determine Design Levels. Because no digital data for either zone map were available, the published 1997 zone map (Figure F-3) was digitized for use in the study. In addition, several states (e.g., Oregon, Washington) implemented the seismic zone assumptions somewhat differently than the original map.

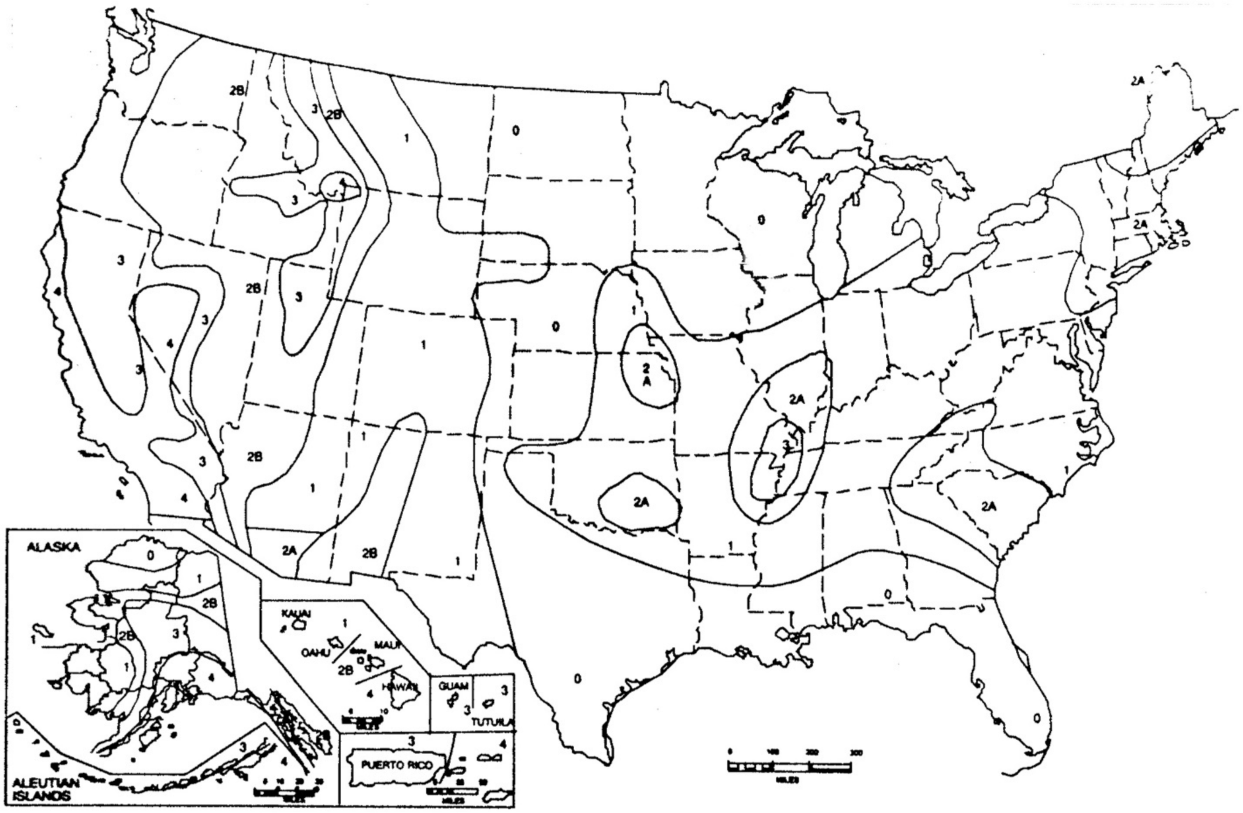


Figure F-3: 1997 UBC Seismic Zone map, as published (ICBO, 1997)

For example, rather than following the zone boundary explicitly, Oregon assigned counties to zones; and in the 1997 UBC, included an area of Zone 4 in the western part of the state, including Curry and Coos Counties, and a “thin band” along the coast (Oregon Department of Land Conservation and Development, 2000). The 1997 UBC zone map, as used in the study, is provided in Figure F-4. The basic seismic zone boundaries did not change significantly from the 1994 UBC (ICBO, 1994) to the 1997 UBC (ICBO, 1997), except as noted above for Oregon.

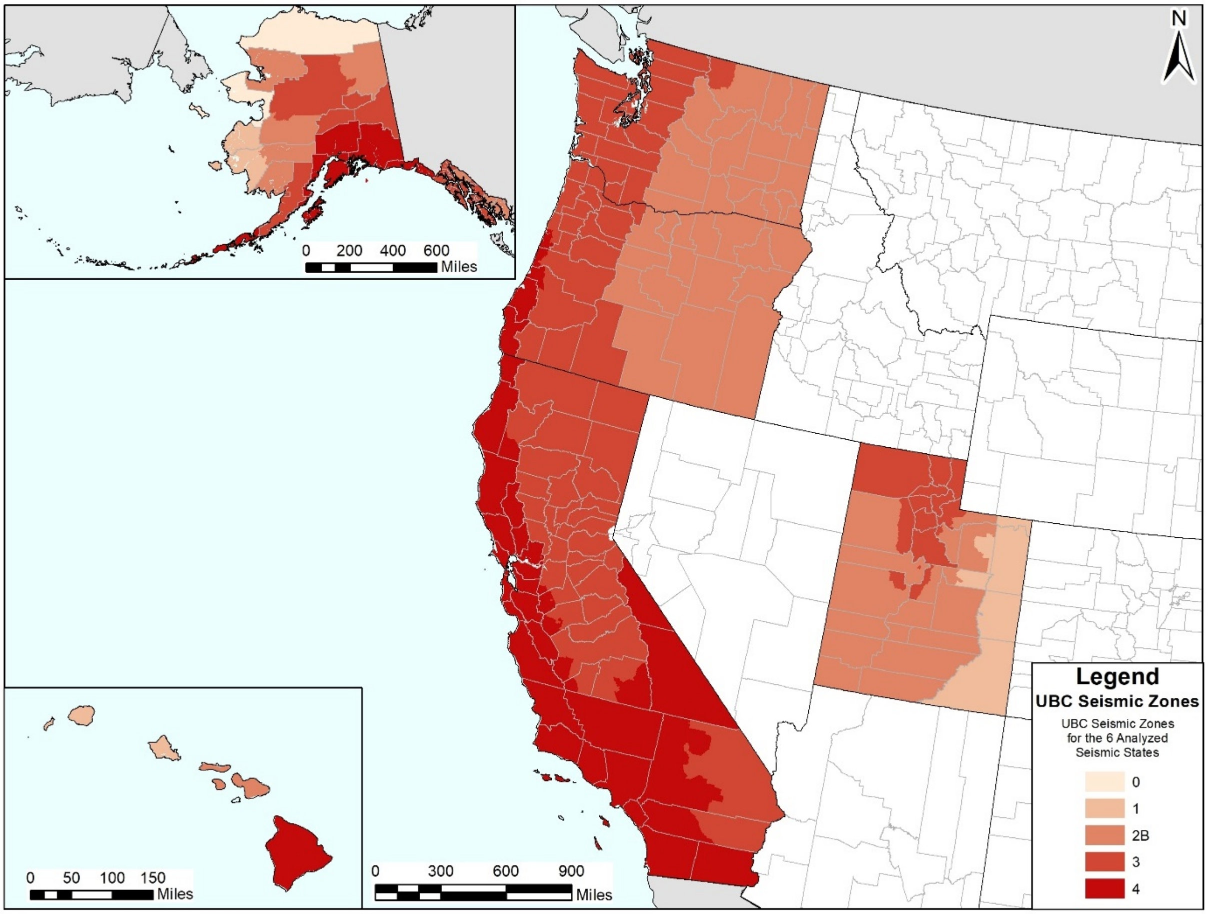


Figure F-4: 1997 UBC Seismic Zone map used in the study

Near-source fault zone data for the 1997 UBC were developed by the California Division of Mines and Geology, now called the California Geological Survey (CGS, 1998). The maps include two types of known active faults: Type A (M7+) and Type B (M6.5 to 7.0); see Figure F-5. Near-source factors were applied to structures within 15 kilometers of Type A faults, or within 10 kilometers of Type B faults. Figure F-6 is an example map of Type A and Type B faults and associated buffer zones. The GIS data for the near-fault zones were provided by CGS personnel for use in the study. These GIS data were used to identify census tracts where near-fault factors apply; these data were used to determine appropriate seismic coefficients, Ca and Cv, which were then used in the determination of Hazus Design Levels.

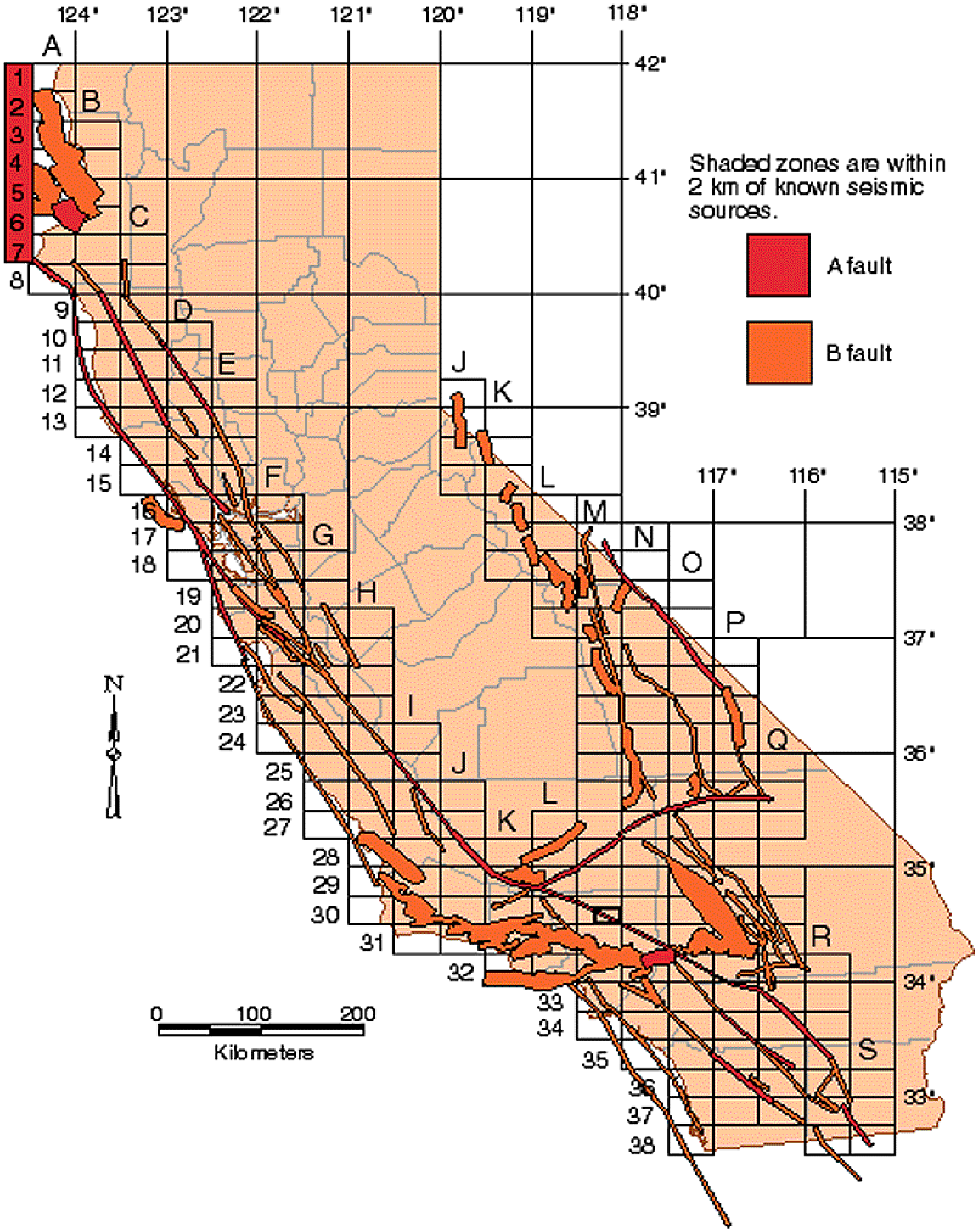


Figure F-5: Index map for active fault near-source maps (CGS, 1998)

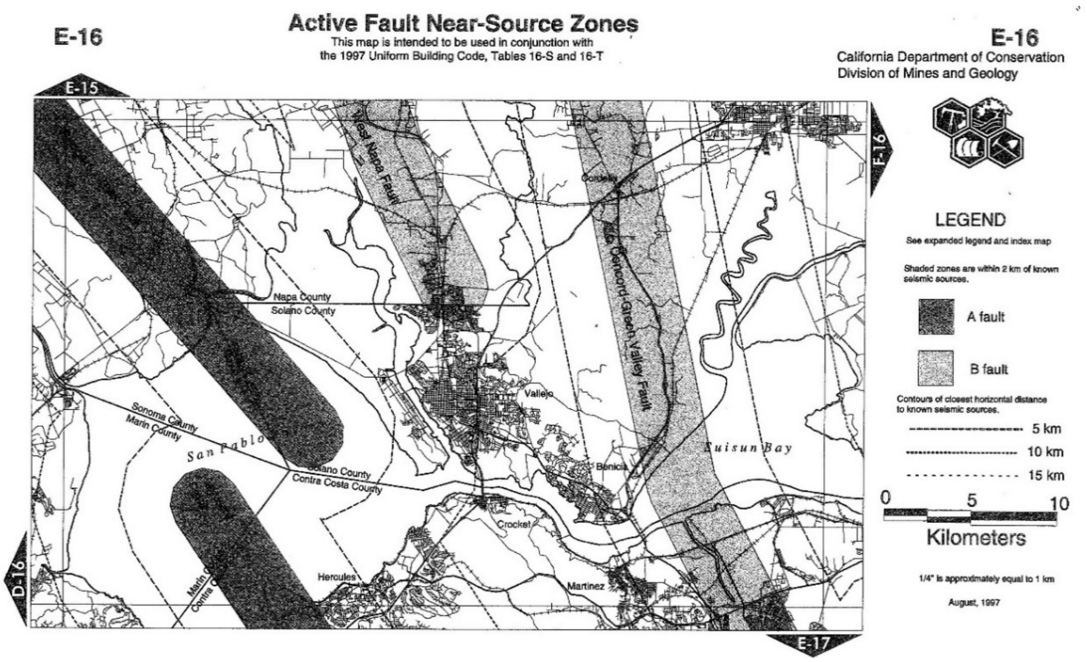


Figure F-6: Example fault near-source zone map (CGS, 1998)

F.2.4 Analysis Prioritization

To focus the Hazus AAL analyses on the counties that were expected to produce the majority of earthquake losses (and losses avoided), should budgetary constraints arrive, an analysis prioritization effort was conducted. Seismic hazard data (2500-year return period peak ground accelerations; see Figure F-1) were overlain onto census tract maps of population to determine county-level, hazard-weighted population statistics. Each county was classified as High (100,000+), Medium (20,000 to 100,000), or Low (<20,000) analysis priority based on the aggregate hazard-weighted population. The classifications are summarized in Table F-2 and shown in Figure F-7. As shown in the table, 85% of the population in the six western seismic states reside in the 45 High-priority counties, and 96% (85% plus 11%) reside in High- and Medium-priority counties. It should be noted, however, that despite the prioritization exercise, all counties with adequate CoreLogic building data were included in the analyses.

Table F-2: County Analysis Prioritization Results for Six Western Seismic States

State	No. of Counties High Priority	No. of Counties Medium Priority	No. of Counties Low Priority	Total	Population in Counties (millions) High Priority	Population in Counties (millions) Medium Priority	Population in Counties (millions) Low Priority	Total (millions)
AK	1	3	25	29	0.29	0.24	0.18	0.71
CA	27	14	17	58	34.63	2.09	0.53	37.25
HI	2	1	2	5	1.14	0.15	0.07	1.36
OR	5	14	17	36	2.48	1.27	0.32	4.08
UT	4	3	22	29	2.08	0.30	0.38	2.76
WA	6	11	22	39	4.37	1.67	0.69	6.72
Total	**45**	**46**	**105**	**196**	**45.00**	**5.73**	**2.17**	**52.89**
%	23%	23%	54%	100%	85%	11%	4%	100%

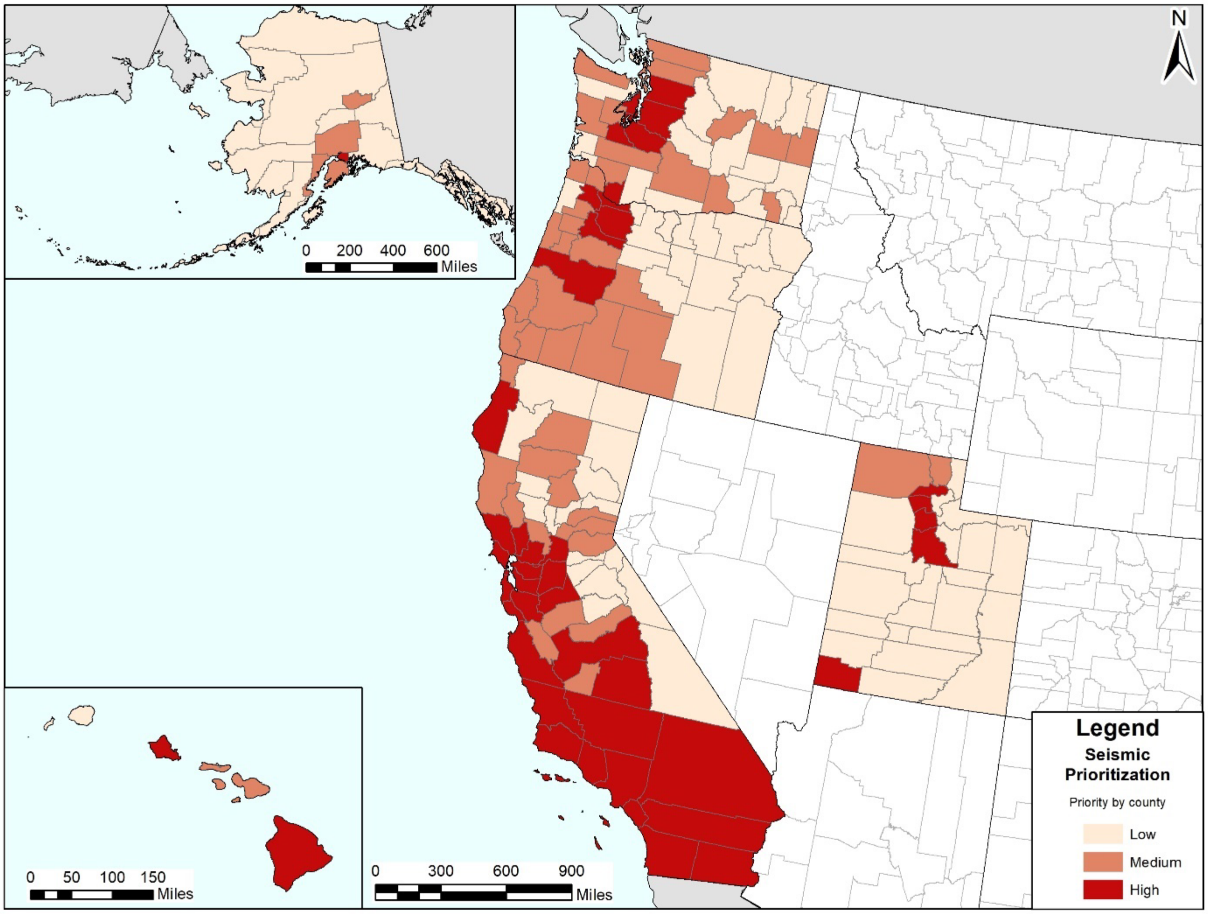


Figure F-7: Seismic analysis prioritization by county for the six western seismic states

F.3 Supplemental Seismic Modeling Methodology

F.3.1 Hazus Design Level Determination

This section describes the development of additional Design Levels, consideration of soil conditions, and Design Level assignments for both commercial and residential (one- and two-family) construction under the various editions on the UBC and IBC.

F.3.1.1 Development of Hazus Design Levels for Exceptionally High Hazard

The Hazus loss estimation methodology is highly dependent on structural lateral strength, which is incorporated into the four standard Hazus Design Levels: *Pre-Code, Low Code, Moderate Code*, and *High Code*. The Design Levels correspond to the mapped seismicity zones of the 1991 and 1994 UBC, as follows:

- *Pre-Code* is used for buildings designed before seismic codes were adopted in a region.
- *Low Code* corresponds to lateral strength ranges appropriate for Zones 1 and 2A.
- *Moderate Code* corresponds to Zones 2B and 3.
- *High Code* corresponds to Zone 4.

The other significant factor in determining code design lateral strength is the structural vibration period of the structure under consideration. This factor is considered in Hazus by using three structural height levels, which roughly mirror structural period values.

The 1997 UBC and 2000 IBC recognized that sites very close to known active faults, mostly in California, would experience shaking far greater than that considered when codes were developed for Zone 4. In the estimation of losses avoided by the adoption of I-Codes or similar codes such as the 1997 UBC, Hazus models with lateral strengths such as those that are required by these codes and that are greater than the original Hazus *High Code* Design Level must be used.

In addition, the IBC series of codes uses mapped contours of hazard level using values of spectral acceleration rather than zones; the original Hazus Design Levels cannot simply be related to zones, but must consider code-specified site shaking. In this study, to extrapolate from the original Hazus architecture and methodology, ranges of shaking levels were equated to each Hazus Code Design Level (*Low Code, Moderate Code*, and *High Code*); and two new, higher levels have been developed in the same format (*Very High Code* and *Severe Code*).

The *Very High Code* Design Level represents shaking (and code strengths) 1.5 times the *High Code* Design Level developed for the traditional Zone 4 hazard. *Severe Code* represents shaking 2.0 times the *High Code* level. Although code strengths and associated Hazus strength parameters are proportional to these factors (1.5 and 2.0), not all the parameters used in the Hazus loss methodology are proportional. The changes made to various parameters are shown in Table F-3.

Table F-3: Hazus Calculation Parameter Changes for New Design Levels

Parameter Change	Very High Code	Severe Code
Capacity curve – adjust design strength and yield/ultimate capacity	Increase by a factor of 1.5	Increase by a factor of 2.0
Structural fragility curve – adjust median spectral displacement values (beta unchanged)	Increase by a factor of 1.15	Increase by a factor of 1.25
Nonstructural acceleration-sensitive fragility curve – adjust median spectral accelerations (beta unchanged)	Increase by a factor of 1.3	Increase by a factor of 1.5
Nonstructural drift-sensitive fragility curve	No change	No change

To test the appropriateness of the new Design Levels, a test was conducted in Hazus for the Model Building Types (MBTs) expected to be dominant in the six western seismic states. Three sample census tracts were populated with the same mix of MBTs. One census tract had *High Code* buildings and a representative *High Code* hazard; the second tract was similar using *Very High Code,* and the third tract used *Severe Code*. Although definitive data that would yield the "correct" losses in these cases are not available, numerical studies of similar issues are available (FEMA, 2006). The losses generated in the tests were compared to the available studies, and the new Design Levels were incorporated into the study. Fifteen percent of the building records in California, representing 18% of the modeled square footage, use the new Design Levels.

Although the code-required strength levels in the 1997 UBC and the IBC series of codes are similar, the mapped hazard parameters are different. In the calculation methodology that was used, the Design Levels were assigned based on mapped hazard parameters. Design Level assignments for the various codes must therefore be developed separately. See Section F.3.1.4 for the development of Design Level assignments for the 1997 UBC, and Section F.3.1.5 for assignments for the IBC code editions.

F.3.1.2 Incorporation of Site Soils Data into Design Level

All seismic codes used in this study determined the strength of shaking expected at a site based on a hazard factor (from a zone in the earlier codes and a site-specific value derived from contour maps in later codes) and a site soil profile. The original Hazus Design Levels (see Section F.3.1.1) assumed a default site coefficient, based on the 1991 UBC soil type S_3 (medium-stiff soil), which modified the hazard factor by 1.5. Although this site coefficient was appropriate for many sites and adequate for the purposes of regional loss estimation, these design codes also had site factors of 1.0 for S_1 sites (very hard soil, rock), 1.2 for S_2 sites (stiff soil), and 2.0 for S_4 sites (very soft soil). Subsequent codes (1997 UBC and the IBC series) included more complex and more wide-ranging site coefficients that varied not only by site class, but also by hazard level. In this study, the site-specific shaking used to determine losses for buildings designed under various codes incorporated a site condition (see Section F.2.2) and associated site coefficient. In most cases, this modification is an amplification; if assumed structural design strengths do not also consider the site coefficient, the estimated losses could be over- or under-estimated, based on the actual site conditions.

To refine the original Hazus Design Levels to consider site soil conditions, code lateral strength calculations were made for structures of various periods on various site soils. The average required design strength (at yield) of structures on the various site conditions were compared with those on S_3 sites (used for original Hazus Design Levels); and under a few extreme conditions, the site soil coefficient changed the Design Level. The large amplification of 2.0 for S_4 sites yielded a code design strength significantly greater than *High Code*, and the stronger Design Levels discussed in Section F.3.1.1 were needed. The modifications to the original Hazus Design Level table based on NEHRP soil types (see Section F.2.2) are shown in Table F-4. The soil type S_3 column in the table corresponds to the published Hazus Design Level table (FEMA, 2012c).

The site soils factor for other codes considered in the study were incorporated in a similar manner.

Table F-4: Design Level Determination for Pre-IBC (1994 UBC), Non-W1 Buildings

UBC Seismic Zone	NEHRP Soil A, B (1994 UBC S_1)	NEHRP Soil C (1994 UBC S_2)	NEHRP Soil D (1994 UBC S_3)	NEHRP Soil E (1994 UBC S_4)
1	Low Code	Low Code	Low Code	Low Code
2A	Low Code	Low Code	Low Code	Moderate Code
2B	Low Code	Low Code	Moderate Code	Moderate Code
3	Moderate Code	Moderate Code	Moderate Code	High Code
4	Moderate Code	High Code	High Code	Very High Code

F.3.1.3 Hazus Design Level Assignments for Pre-IBC Commercial Construction

As previously indicated, the pre-IBC code (in areas where the 1997 UBC was adopted) was taken to be the 1994 UBC. Therefore, with the incorporation of site soil factors into the Hazus Design Levels, the 1994 UBC code design equations could be used directly for assignment of Hazus Design Levels for pre-IBC construction. For any given site, Table F-4 can be used for seismic zone and NEHRP soil type to assign the Hazus Design Level. A map of the resulting pre-IBC Design Levels for commercial construction by census tract for the six western seismic states is provided in Figure F-8.

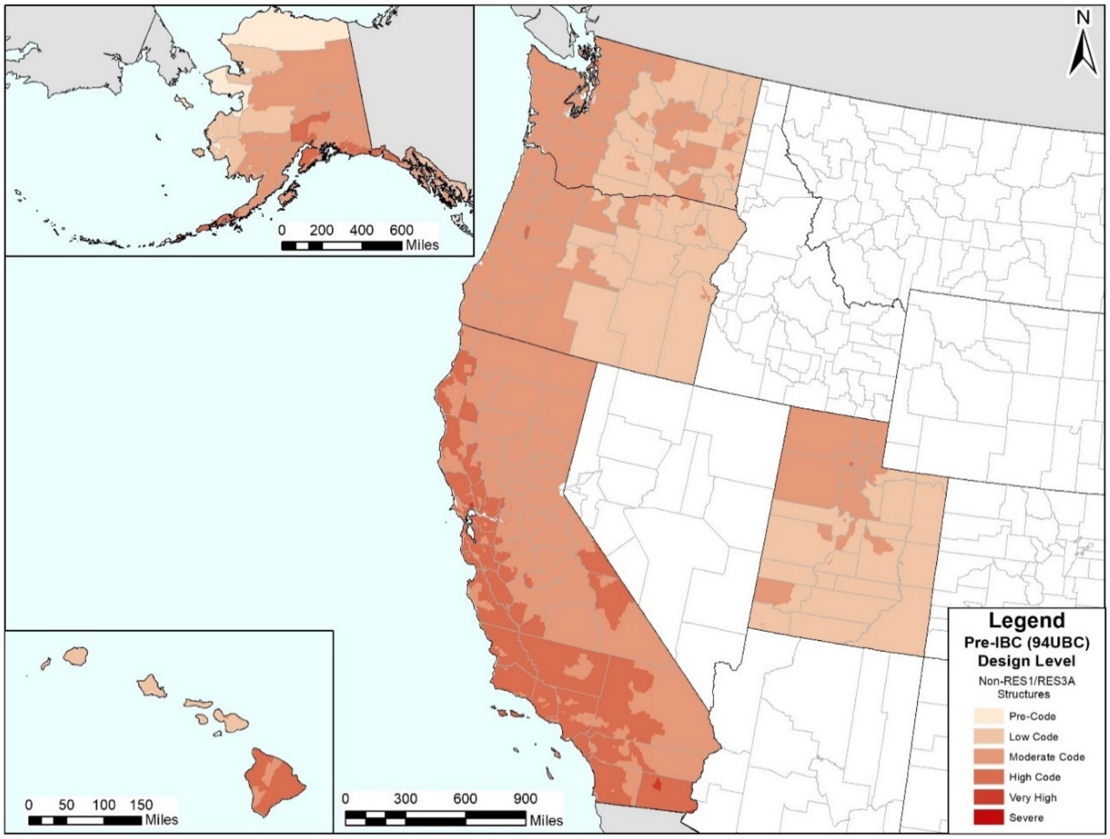


Figure F-8: Pre-I-Code Design Levels for commercial construction by census tract

F.3.1.4 Hazus Design Level Assignments for Commercial Construction under the 1997 UBC

The 1997 UBC introduced new terms into the lateral force design formula: Ca, the acceleration-related seismic coefficient (for short period buildings); and Cv, the velocity-related seismic coefficient (for longer period buildings). The values of these coefficients are between 0.1 and 0.4, which are parallel with traditional UBC zone values. As indicated in Section F.3.1.1, near-fault factors are used to amplify hazard values near major faults. Ca and Cv are the product of hazard values and site soil profiles, and are far more complex than those used in the 1994 UBC, as shown in Table F-5 and Table F-6.

Table F-5: Seismic Coefficient Ca from the 1997 UBC

Soil Profile[1]	Zone 1	Zone 2A	Zone 2B	Zone 3	Zone 4[2]
S_A	0.06	0.12	0.16	0.24	0.32 x Na
S_B	0.08	0.15	0.20	0.30	0.40 x Na
S_C	0.09	0.18	0.24	0.33	0.40 x Na
S_D	0.12	0.22	0.28	0.36	0.44 x Na
S_E	0.19	0.30	0.34	0.36	0.36 x Na

(1) See Table F-1 for definitions of NEHRP Soil Classes

(2) Na = Near-source factor ranging from 1.0 to 1.5, determined based on distance to mapped seismic sources

Table F-6: Seismic Coefficient Cv from the 1997 UBC

Soil Profile[1]	Zone 1	Zone 2A	Zone 2B	Zone 3	Zone 4[2]
S_A	0.06	0.12	0.16	0.24	0.32 x Nv
S_B	0.08	0.15	0.20	0.30	0.40 x Nv
S_C	0.13	0.25	0.32	0.45	0.56 x Nv
S_D	0.18	0.32	0.40	0.54	0.64 x Nv
S_E	0.26	0.50	0.64	0.84	0.96 x Nv

(1) See Table F-1 for definitions of NEHRP Soil Classes

(2) Nv = Near-source factor ranging from 1.0 to 2.0, determined based on distance to mapped seismic sources

Code design strength calculations were run for various MBTs and various vibration periods, and compared to the design strengths associated with the original Hazus Design Levels plus the new Design Levels discussed in Section F.3.1.1(see Table F-7). With this process, it was possible to directly relate Ca and Cv to appropriate Hazus Design Levels. However, due to the separation of the Ca and Cv coefficients, it was also possible to relate Ca values to the Hazus low-rise, and Cv to the mid-/high-rise categories. Ca and Cv can be calculated from seismic hazard (including the near-source factor, if applicable) and soil profile type, enabling use of Table F-7 to assign the Design Level.

Table F-7: Design Level Assignments for Commercial Construction under the 1997 UBC

Design Level	Low-Rise (Non-W1) Construction	Mid- and High-Rise Construction
Low Code	0.16 ≥ Ca	0.2 ≥ Cv
Moderate Code	0.33 ≥ Ca >0.16	0.45 ≥ Cv >0.2
High Code	0.5 ≥ Ca >0.33	0.65 ≥ Cv >0.45
Very High Code	0.75 ≥ Ca >0.5	0.8 ≥ Cv >0.65
Severe Code	Ca >0.75	Cv >0.8

F.3.1.5 Hazus Design Level Assignments for Commercial Construction under the IBC

The IBC seismic codes introduced a new hazard mapping scheme in 2000. Spectral acceleration values determining the short period region of a design response spectrum, S_S, were mapped by contours. Similarly, values determining the longer-period range (velocity range) of the design spectrum, S_1, were also mapped by contours. Similar to the 1997 UBC, factors based on site soil profiles were used to convert the mapped values to represent shaking expected at the site in the form of a response spectrum; see Table F-8 and Table F-9. Formulae were then used to convert the response spectrum into lateral force design values considering the structural period and the characteristic of the structural system.

Similar to the 1997 UBC, code design lateral strength calculations were run for a variety of MBTs and building periods, and the results related to Table F-8 and Table F-9, enabling development of Table F-10. In Table F-10, S_{DS} and S_{D1} (short- and long-period spectral values developed by code formula based on mapped hazard values and site soils factors) were used as determining parameters.

Table F-8: Site Class Modification of Mapped Hazard Values in the IBC:
Site Coefficient Fa, Short-Period Spectral Response Acceleration Parameter

Site Class(1)	$S_S \leq 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9

(1) See Table F-1 for definitions of NEHRP Soil Classes

Table F-9: Site Class Modification of Mapped Hazard Values in the IBC:
Site Coefficient Fv, 1.0-Second Period Spectral Response Acceleration Parameter

Site Class(1)	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.40$	$S_1 \geq 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4

(1) See Table F-1 for definitions of NEHRP Soil Classes

Table F-10: Design Level Assignments for the IBC Code Series for Commercial Construction

Design Level	Low-Rise (Non-W1) Construction	Mid- and High-Rise Construction
Low Code	$S_{DS} < 0.45$	$S_{D1} < 0.2$
Moderate Code	$0.45 \le S_{DS} < 0.9$	$0.2 \le S_{D1} < 0.4$
High Code	$0.9 \le S_{DS} < 1.4$	$0.4 \le S_{D1} < 0.8$
Very High Code	$1.4 \le S_{DS} < 1.75$	$0.8 \le S_{D1} < 1.15$
Severe Code	$S_{DS} \ge 1.75$	$S_{D1} \ge 1.15$

After the initial IBC was published in 2000, new editions were published every 3 years. Although the contoured hazard maps were slightly different, the basic code calculations for lateral strength were the same. Therefore, Table F-10 can be used for all IBC code editions with only the hazard maps changing. To determine the appropriate Design Levels for each census tract under each edition of the I-Codes (IBC and IRC), census tract centroids and soil data were entered into the USGS's design ground motion calculator tools (web services accessed via MATLAB, see https://earthquake.usgs.gov/ws/designmaps/) to estimate S_{DS} and S_{D1}. As an example, maps of the resulting Design Levels under the 2006/2009 IBC are given by census tract for the six western seismic states in Figure F-9 for low-rise commercial construction, and in Figure F-10 for mid- and high-rise commercial construction.

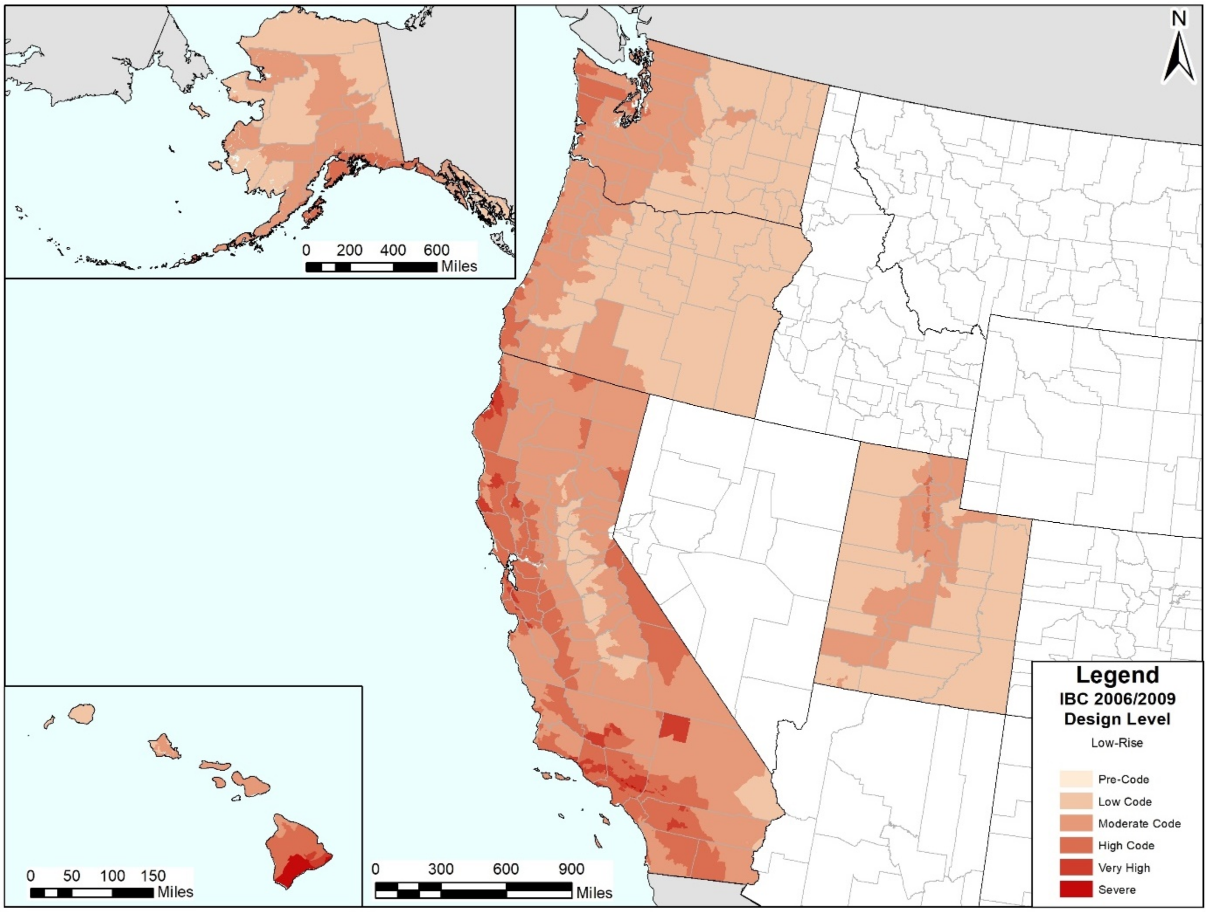


Figure F-9: 2006/2009 IBC Design Levels for low-rise commercial construction by census tract

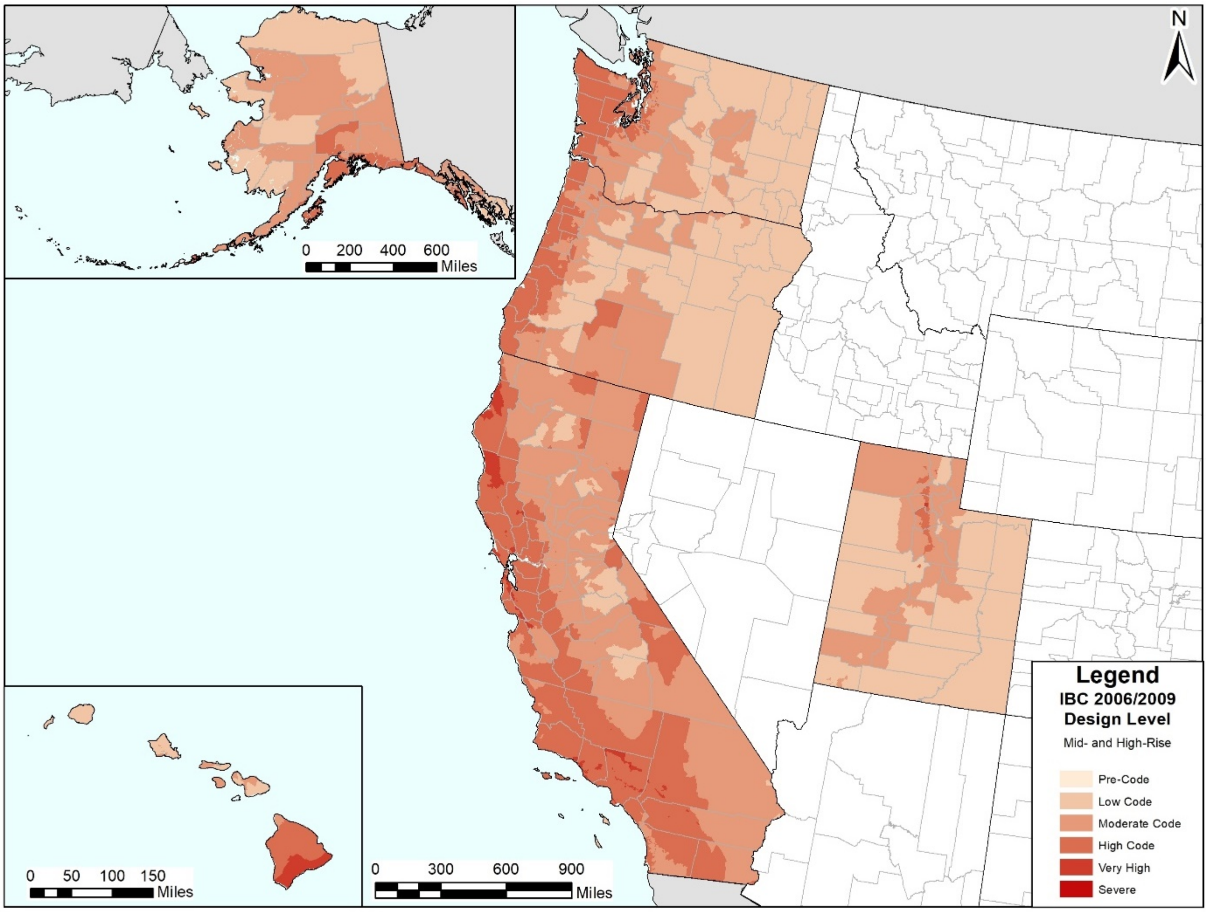


Figure F-10: 2006/2009 IBC Design Levels for mid- and high-rise commercial construction by census tract

F.3.1.6 Hazus Design Level Assignments for Residential Construction under the 1994 UBC

As discussed in Section 6.1.2, residential one- and two-family dwellings have been built in seismic regions according to the prescriptive provisions in the UBC referred to as “conventional construction” since 1994. Because of the prescriptive nature of the provisions, broad interpretation, and poor enforcement, conventional construction has been given a Hazus Design Level of *Moderate Code*. Such practice did not consider the local seismic hazard, and the same rules were used in both UBC Seismic Zones 3 and 4. It is unlikely that the earthquake bracing provisions of conventional construction were used in low-hazard zones such as UBC Seismic Zones 1, 2A, and 2B, and these structures have been considered *Low Code*.

Larger homes were often designed by architects and engineers, and have been assumed to be constructed in accordance with seismic building codes. In this study, a building area of 2000 square feet was used to differentiate conventional construction from fully engineered construction. The Design Levels assigned to these buildings are shown in Table F-11, with conventional construction in the “small” column and fully engineered construction in the “large” column. Maps of the resulting Design Levels are given by census tract for the six western seismic states in Figure F-11 for small (≤ 2000 square feet) residential construction, and in Figure F-12 for large (>2000 square feet) residential construction. However, it is assumed that there was much less engineered design of residential structures in Alaska before 2000, and use of the area modifier for pre-I-Code codes is not recommended. Therefore, in Alaska, the Design Levels for the conventional construction (small building) category were used for all residential construction under the 1994 UBC.

Table F-11: Design Level Assignments for One- and Two-Family Residential Construction under the 1994 UBC

UBC Seismic Zone	Conventional Construction (Small, ≤ 2000 SF)	Fully Engineered Construction (Large, > 2000 SF)
1	Pre-Code	Pre-Code
2A	Low Code	Low Code
2B	Low Code	Low Code
3	Moderate Code	Moderate Code
4	Moderate Code	High Code

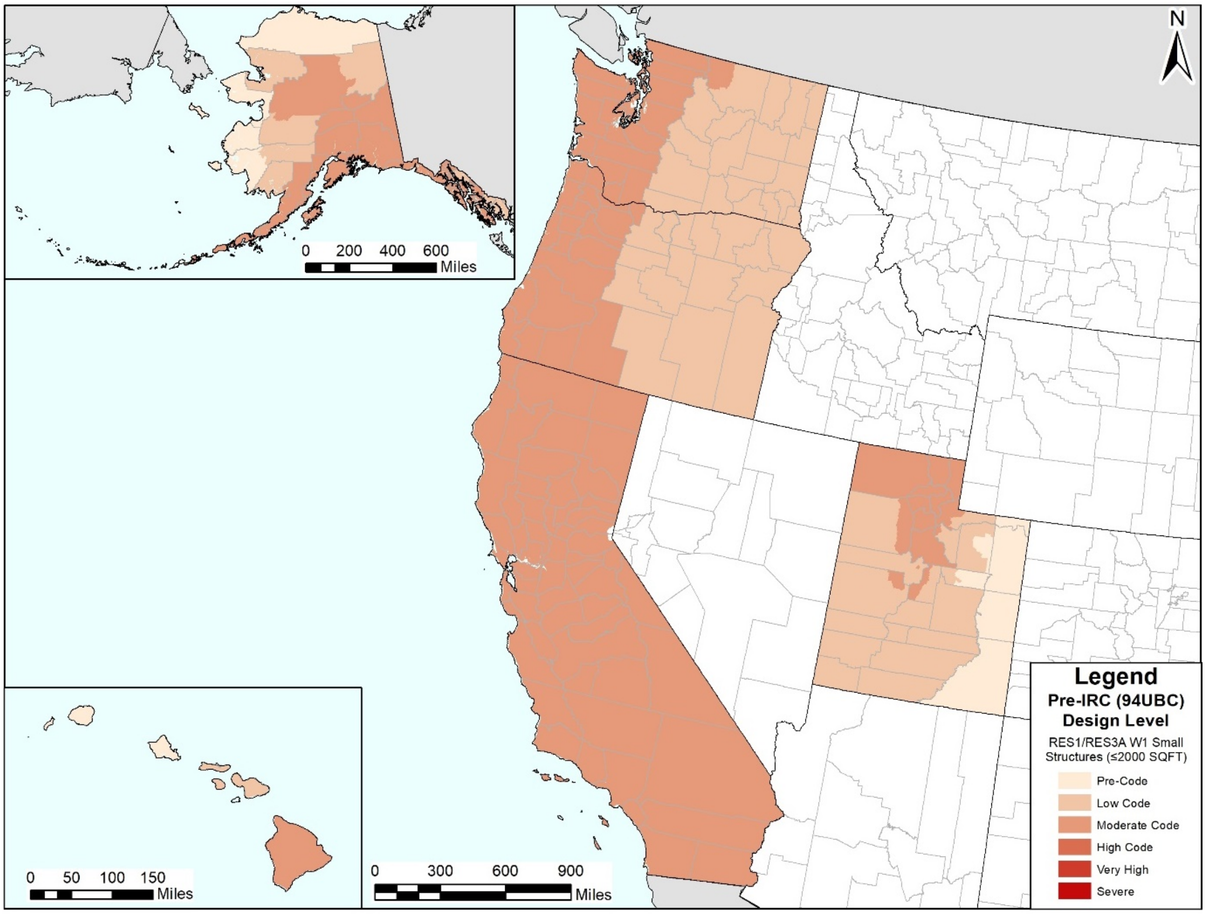


Figure F-11: Pre-IRC Design Levels for small one- and two-family residential construction by census tract

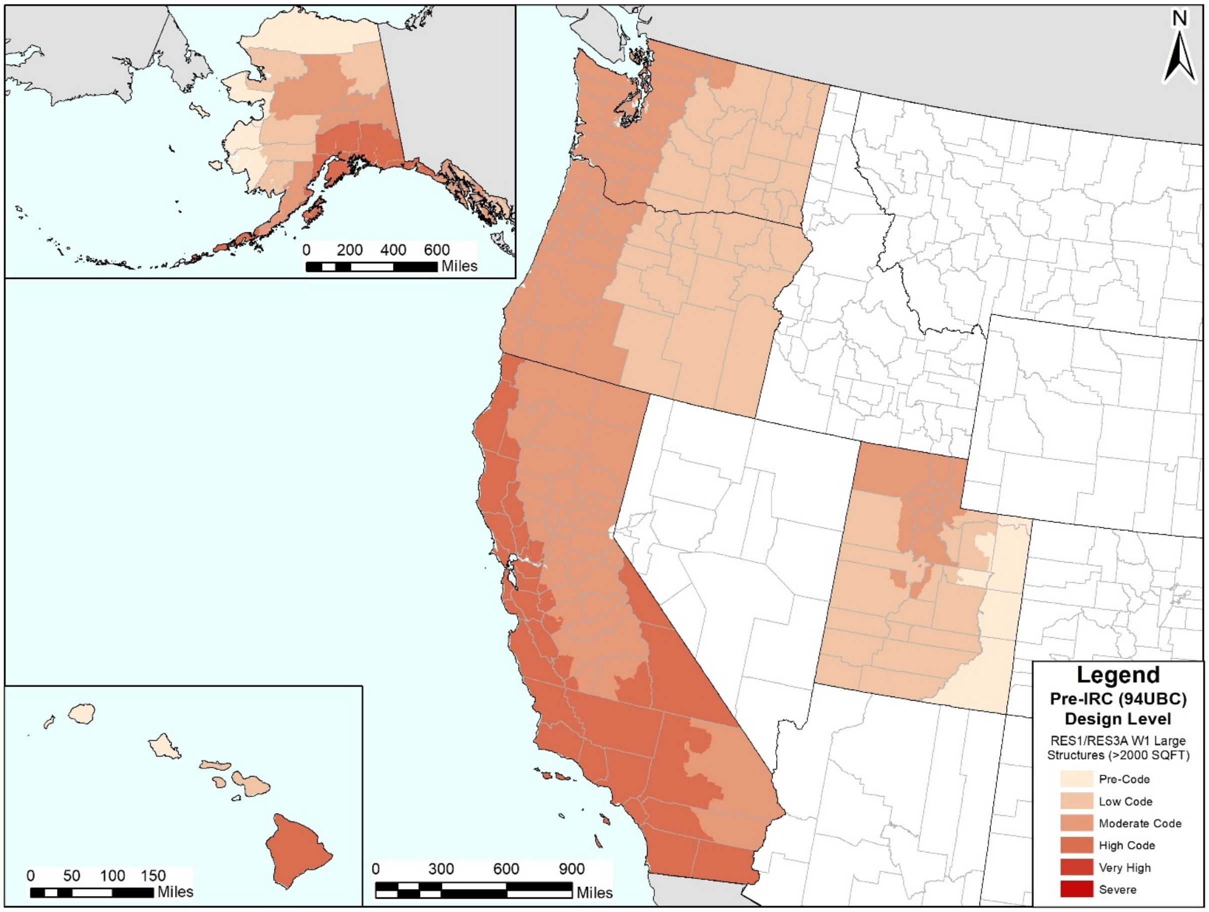


Figure F-12: Pre-IRC Design Levels for large one- and two-family residential construction by census tract

F.3.1.7 Hazus Design Level Assignments for Residential Construction under the 1997 UBC

Conversations with Structural Engineers specializing in residential construction in Southern California, Northern California, and Oregon indicated that almost all residential sub-developments and larger homes were designed by code rather than built using conventional construction practices after the 1997 UBC was published. However, smaller, “one-off” homes were probably still built using conventional construction practices. For the 1997 UBC, the building square footage used to differentiate the two practices was lowered from the 2000 square feet used for the 1994 UBC Design Levels, to 1500 square feet.

Design Level assignments for small residential buildings are the same in the 1994 UBC and 1997 UBC. However, for the large-category (>1500 square feet), code-designed buildings under the 1997 UBC could be subject to near-field amplifications (see Section F.3.1.4). These residential buildings would therefore be designed to the same criteria as the full 1997 UBC in the near-field regions. These Design Level assignments are summarized in Table F-12. As noted in the previous section, it is assumed that there was less engineered design of residential structures in Alaska than in the other states in this study, and the size threshold for engineered construction was increased from 1,500 square feet to 2,000 square feet.

Table F-12: Design Level Assignments for One- and Two-Family Residential Construction under the 1997 UBC

UBC Seismic Zone	Conventional Construction (Small, ≤ 1500 SF)	Engineered Construction (Large, >1500 SF)
1	Pre-Code	Pre-Code
2A	Low Code	Low Code
2B	Low Code	Moderate Code
3	Moderate Code	Moderate Code
4	Moderate Code	High Code
Near Field	Moderate Code	High Code, Very High Code, or Severe Code based on Ca criteria for Low-Rise Non-W1

F.3.1.8 Hazus Design Level Assignments for Residential Construction for all Editions of the International Residential Code

Design Level assignments for the IRC are similar to the 1997 UBC, with three exceptions: (1) the IRC (also the IBC) replaces the UBC hazard zones with spectral acceleration contours (see Section F.3.1.5); (2) seismic design considerations were not required for sites with S_{DS} (short-period spectral values developed by code formula based on mapped hazard values and site soils factors) less than 0.5; and (3) the prescriptive construction rules in the IRC (parallel to conventional construction) are limited to areas with S_{DS} of less than 1.17. Residential buildings on sites with a greater hazard were required to be designed to full code.

Considering the development of Table F-10 for short-period buildings under the IBC and Table F-12 for residential construction under the 1997 UBC, and the exceptions described above, Table F-13 can be constructed covering residential construction under the IBC. As an example, maps of the resulting Design Levels under the 2006/2009 IRC are given by census tract for the six western seismic states in Figure F-13 for small residential construction (≤1500 square feet), and in Figure F-14 for large residential construction (>1500 square feet).

As noted in the previous section, it was assumed that there was less engineered design of residential structures in Alaska than in the other states in this study, and the size threshold for engineered construction was increased from 1,500 square feet to 2,000 square feet.

Table F-13: Design Level Assignments for One- and Two-Family Residential Construction for the IRC Code Series

Design Level	Conventional Construction (Small W1, ≤ 1500 SF)	Engineered Construction (Large W1, >1500 SF)
Low Code	$S_{DS} < 0.5$	$S_{DS} < 0.45$
Moderate Code	$0.5 \le S_{DS} < 1.17$	$0.45 \le S_{DS} < 0.9$
High Code	$1.17 \le S_{DS} < 1.4$	$0.9 \le S_{DS} < 1.4$
Very High Code	$1.4 \le S_{DS} < 1.75$	$1.4 \le S_{DS} < 1.75$
Severe Code	$S_{DS} \ge 1.75$	$S_{DS} \ge 1.75$

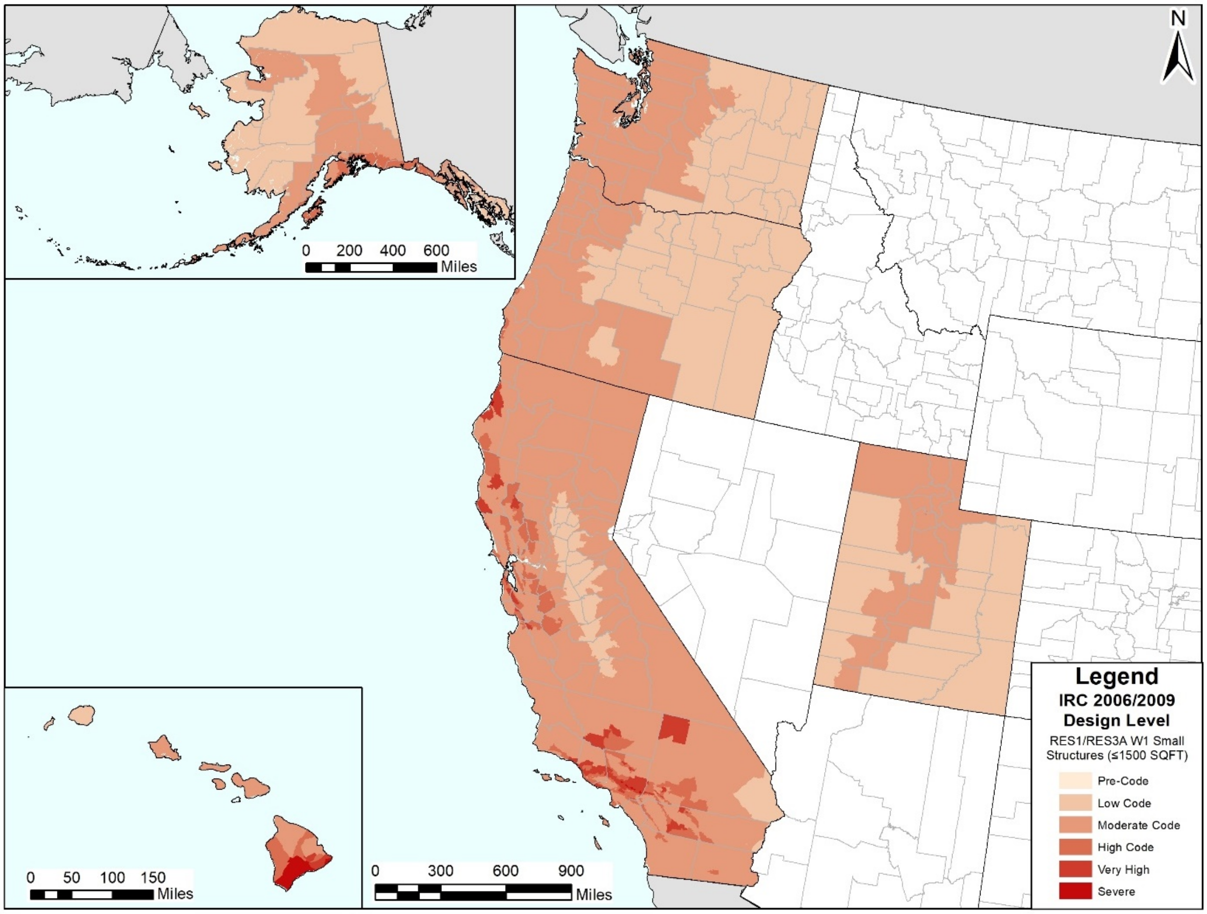


Figure F-13: 2006/2009 IRC Design Levels for small one- and two-family residential construction by census tract

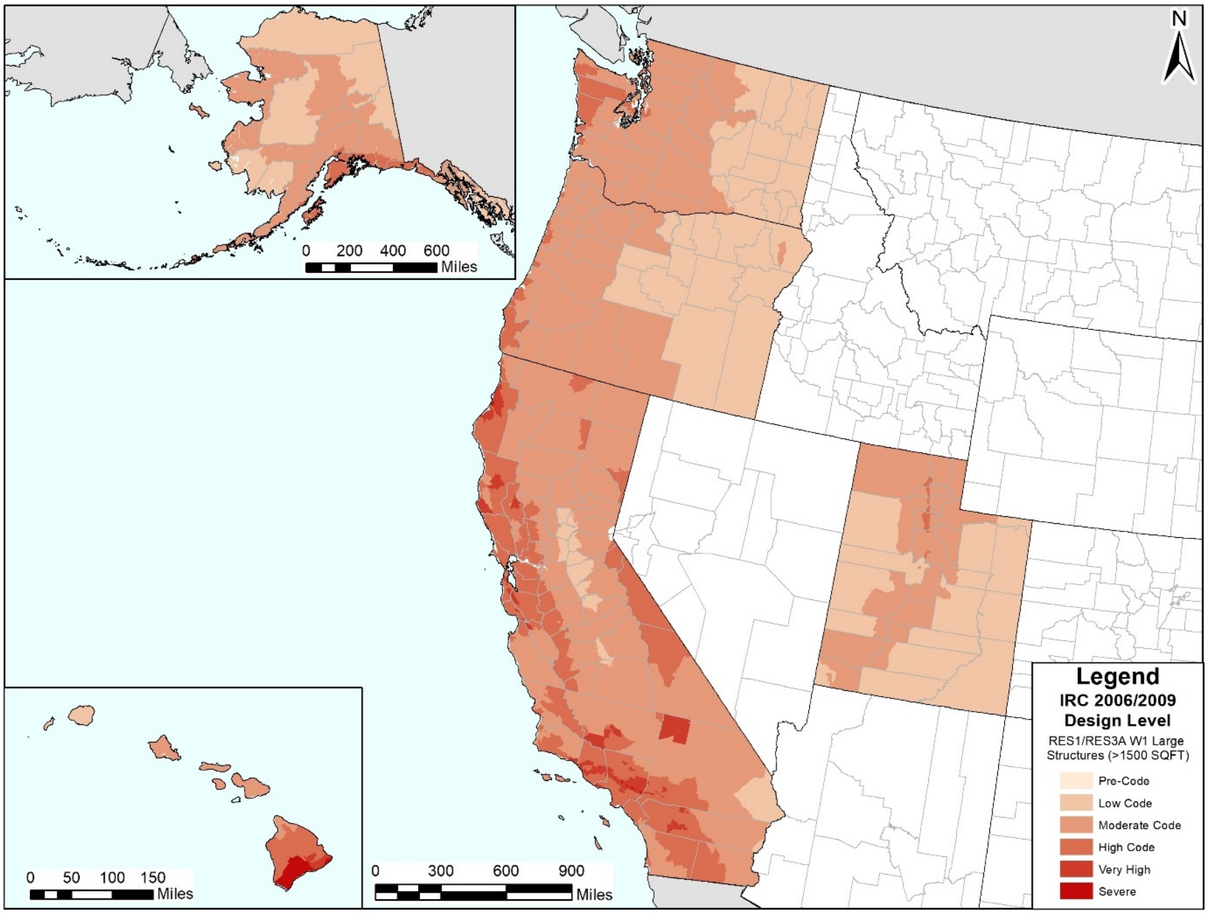


Figure F-14: 2006/2009 IRC Design Levels for large one- and two-family residential construction by census tract

F.3.2 Hazus Model Building Type Determination and Required Data

F.3.2.1 Height Proxy Approach

Because the CoreLogic parcel data for some counties were missing data on the number of stories, it was determined that a proxy approach would be required to adequately characterize buildings without stories data into Hazus height categories: low-rise (one to three stories), mid-rise (four to seven stories), and high-rise (eight or more stories).

Construction profile summaries of each state's database were developed for the determination of the MBT, which included characterizing each building record by:

- Hazus Occupancy Class (see Table 3-1)
- Square footage: Small (<2,500 square feet), medium (2,500 to 20,000 square feet), or large (>20,000 square feet)
- Height: Groupings of stories that varied by occupancy, including subclasses of the height categories. For example, for selected commercial occupancies (COM2, COM4, COM7,

and COM8, see Table 3-1), construction was categorized as 0 story (no height data), one to two stories (low-rise), three stories (low-rise), four to seven stories (mid-rise), and eight or more stories (high-rise). The two low-rise sub-classes reflect potential differences in construction type (i.e., wood frame and steel frame, respectively).

For many of the “0 story” profiles, occupancy class and building size were sufficient to make an assumption about the building’s MBT, so a height proxy was not required. For example, small and medium single-family dwellings (RES1) are assumed to be light wood frame (MBT W1), so no additional height information was required.

Construction profiles requiring an assessment of height class prior to determination of MBT included:

- Large COM1
- Large COM4
- Medium COM10
- Large COM10
- Large EDU1
- Large GOV1
- Large RES3B/RES3C/RES3D
- Large RES3E/RES3F
- Large RES4
- Large RES6

For these ten profile groups, the relevant building data for each state were extracted, along with data on the area of each parcel, to facilitate the calculation of construction density (building area, in square feet, divided by parcel area, in square feet).

For each construction profile, an iterative analysis was undertaken by state using the available building data for each construction profile to manually identify low- and high-rise density thresholds that (1) maximized the number of buildings that were correctly characterized into their true Hazus height class; and (2) produced total height class assignments best matching the actual distribution.

The final density thresholds used in each state are provided in Table F-14; states are listed in the order in which they were analyzed. Buildings with a construction density of less than the low-rise threshold were assumed to be low-rise; buildings with a density greater than the high-rise threshold were assumed to be high-rise. The remainder were assumed to be mid-rise.

In some cases, such as for medium COM10 buildings in the California database or large COM1 buildings in the Oregon and Alaska databases, it was concluded from the available data that the

“0” stories buildings would all be considered low-rise; these cases are identified in Table F-14 by a “9999” in the low-rise density threshold column, and a “99999” in the high-rise column, effectively assigning all buildings to the low-rise category. Similarly, buildings that are either low- or mid-rise (e.g., COM1 buildings in California) have a “9999” in the high-rise threshold column, effectively eliminating high-rise from the assignments.

Table F-14: Construction Density(1) Thresholds Used to Determine Height Class for Selected Large Buildings and Medium COM10 Buildings

Hazus Occupancy Class(2)	California		Oregon		Washington		Utah		Alaska		Hawaii	
	Low-Rise	High-Rise	Low-Rise	High-Rise	Low-Rise	High-Rise	Low-Rise	High-Rise	Low-Rise	High-Rise	Low-Rise	High-Rise
COM1	2.4	9999(3)	9999(3)	99999(3)	2.8	14	2.3	9999(3)	9999(3)	99999(3)	-(4)	-(4)
COM4	3.5	7	3.2	17.5	1.27	9.2	4.4	9999(3)	9999(3)	99999(3)	9999(3)	99999(3)
COM10 Large	0.75	3.5	-(4)	-(4)	1.9	21	-(5)	-(5)	-(5)	-(5)	-(4)	-(4)
COM10 Medium	9999(3)	99999(3)	-(4)	-(4)	0.42	9999(3)	-(5)	-(5)	9999[c]	99999[c]	-(4)	-(4)
EDU1	-(4)	-(4)	9999(3)	99999(3)	9999(3)	99999(3)	-(5)	-(5)	-(4)	-(4)	-(4)	-(4)
GOV1	-(4)	-(4)	9999(3)	99999(3)	-(4)	-(4)	-(4)	-(4)	-(4)	-(4)	-(4)	-(4)
RES3B	1.84	9999(3)	9999(3)	99999(3)	2.75	8.2	4.4	9999(3)	-(5)	-(5)	-(5)	-(5)
RES3C	1.84	9999(3)	9999(3)	99999(3)	2.75	8.2	4.4	9999(3)	-(5)	-(5)	-(5)	-(5)
RES3D	1.84	9999(3)	9999(3)	99999(3)	2.75	8.2	4.4	9999(3)	-(5)	-(5)	-(5)	-(5)
RES3E	1.75	5.5	12.0	9999(3)	1.05	11.2	12.6	9999(3)	-(4)	-(4)	-(4)	-(4)
RES3F	1.75	5.5	12.0	9999(3)	1.05	11.2	12.6	9999(3)	-(4)	-(4)	-(4)	-(4)
RES4	0.63	2.8	-(4)	-(4)	0.61	6.1	-(4)	-(4)	9999(3)	99999(3)	-(6)	-(6)
RES6	-(4)	-(4)	-(4)	-(4)	0.93	6.5	-(4)	-(4)	-(4)	-(4)	-(4)	-(4)

(1) Density is estimated as building area (square feet) divided by parcel area (square feet)

(2) See Table 3-1 for the Hazus Occupancy Class definitions

(3) 9999 and 99999 are used as the threshold to limit the assignments to low-rise, or low- and mid-rise only

(4) N/A – not included in state's top occupancies

(5) N/A – no buildings in this class have "0" stories data

(6) data insufficient to proxy, visual review conducted

F.3.2.2 Model Building Type

Building structure type is an essential parameter for modeling losses from seismic hazards. “Construction Type” data stored in the CoreLogic database were reviewed for use in determining structure type for each parcel in the dataset. Unfortunately, very few of the parcels had “Construction Type” data. In addition, the “Construction Type” entries often could not be used to assign the appropriate Hazus MBT, which is needed for the Hazus loss calculations. Therefore, the MBT had to be deduced from other information available in the CoreLogic data.

Parameters commonly found in the data that informed the selection of Hazus MBT were:

- Building occupancy
- Building size (square footage)
- Number of stories in the building

In this study, this set of data for a given building is referred to as a construction profile. Given these parameters, structural engineers who work in the target region can generally deduce the MBT, using their knowledge of construction practices; the demands of space use; and economics for the period of time in question.

The occupancies used to define the construction profiles were the occupancies that are defined in Hazus (see Table 3-1). As noted in the previous section, the building size was defined as small (< 2,500 square feet), medium (≥2,500 square feet and ≤ 20,000 square feet), and large (>20,000 square feet), which is often sufficient to identify a likely MBT. The number of stories categories that were used do not correspond completely with the categories in the definition of Hazus MBTs (typically, low-rise: one to three stories; mid-rise: four to seven stories; and high-rise: eight+ stories). The number of stories categories in Hazus were defined more for their dynamic earthquake response properties than as an identifier of structural material and lateral force system. In fact, it was more useful to change construction profile definitions to suit common construction practices. For example, retail trade (COM1) was divided into groups of one story and two to three stories; large, one-story big-box retail buildings built recently in the West are most often reinforced-masonry bearing wall buildings or pre-case concrete tilt-up wall buildings (MBT RM1L, or PC1, respectively; see Table 6-1), whereas large two- to three-story retail buildings are often steel-braced frame structures (MBT S2L).

Construction profiles in California were developed first, and studied by county, groups of counties, and for the state as a whole. Statewide in California, over 400 construction profiles were initially identified. To understand the significance of the construction profiles to which the MBTs would be assigned in a given region, the percent of total square feet represented by each profile was calculated. The MBT identification process can then concentrate on the construction profiles that represent the majority of the building area.

One challenge in selecting MBTs based on the construction profiles of individual counties or on groups of counties was that the number of construction profiles with significant amounts of square footage in areas smaller than the state as a whole resulted in many more different construction profiles than for the state. For example, in the State of California, there were 18 construction profiles that represented more than 1% of the total square footage in the state. While at the county level, there were 41 different construction profiles that represented more than 1% of the total square footage in 13 different California county groups. There were even more construction profiles when individual counties were considered in this manner. The next challenge was to judge whether a construction profile could be represented by the same MBT regardless of its location in the state. It was judged by the in-house structural engineers, both California practitioners, that there were little differences among profiles based on a region defined as the state as a whole.

An example for California construction profiles is provided in Table F-15. In California, the top 50 profiles represented 97% of the total building area for the state. Construction profiles with a large percentage of the square footage distribution were deemed most important to study. Construction profiles listed with less than 1% of the building square footage for the statewide inventory will have little effect on the Hazus calculations. The sum of the 38 listed construction profiles' square footage is 95% of the statewide total for California. For California, the MBTs have been assigned to the construction profiles using in-house engineering experience in California for the last 20 years.

For California, MBTs were identified for construction profiles considering a statewide region. Because the in-house structural engineers do not routinely practice in Oregon, Washington, Utah, Alaska, and Hawaii, at least two local engineers in each of these other states were consulted to identify the likely MBT for the dominant profiles in those states. Because the local engineers were asked to volunteer their time, a statewide region was also used to group the profiles and determine their statistical significance in each state. This was done to limit the number of profiles for which the local engineers were asked to identify MBTs. Because most engineers are not familiar with Hazus or the structural types being used to model the building inventory, a set of model building types almost identical to those used by Hazus, taken from FEMA 547, *Techniques for the Seismic Rehabilitation of Existing Buildings* (FEMA, 2007b), was provided to the local engineers prior to the interview. Differences in opinions amongst local engineers were resolved by in-house engineers involved in the study. The balance of MBTs was selected by in-house professional judgment, based on the input from local engineers. Table F-16 lists the engineers that provided input about local MBTs. Table F-17 through Table F-21 show construction profiles used to interview local engineers in Oregon, Washington, Utah, Alaska, and Hawaii (in the order in which the interviews were completed), the percentage of statewide square footage represented by the construction profiles, and the resulting MBTs. As can be seen in some of these tables, construction profiles with more refined story height data were sometimes grouped into construction profiles using the standard Hazus height classes to reduce the number of profiles to be discussed with the local engineers.

Table F-15: Partial List of California Construction Profiles and Model Building Types

Construction Profile: Occupancy[(1)] Size Stories	Profile % of Statewide Square Footage	Model Building Type[(2)]
RES1_Medium_1_to_3	21.8%	W1
RES1_Small_1_to_3	19.8%	W1
RES1_Medium_0	12.0%	W1
RES1_Small_0	7.1%	W1
RES3EF_Large_1_to_3	4.9%	W2
COM2_Large_1_to_2	3.6%	PC1
RES3BCD_Large_1_to_3	3.0%	W2
COM2_Large_0	2.6%	PC1
RES3BCD_Medium_1_to_3	2.3%	W2
RES3BCD_Medium_0	2.1%	W2
COM1_Large_Low	1.7%	RM1L
COM4_Large_1_to_2	1.3%	S2L
RES3EF_Large_Low	1.1%	W2
COM1_Large_1	1.0%	RM1L
RES3EF_Large_Mid	1.0%	W2
IND2_Large_0	0.8%	S3
RES3EF_Large_4_to_5	0.8%	W2
COM1_Medium_0	0.7%	W2
COM4_Large_4_to_7	0.6%	S1M
RES3A_Medium_0	0.6%	W1
COM4_Large_Low	0.5%	S2L
COM1_Medium_1	0.5%	W2
COM2_Medium_1_to_2	0.4%	PC1
RES3A_Small_0	0.4%	W1
IND2_Large_1	0.4%	S3
COM10_Large_Low	0.4%	PC2L
RES3A_Small_1_to_3	0.4%	W1
RES3A_Medium_1_to_3	0.4%	W1
COM4_Medium_1_to_2	0.4%	W2
COM2_Medium_0	0.4%	PC1
IND2_Medium_0	0.3%	S3
COM4_Medium_0	0.3%	W2
COM4_Large_8+	0.3%	S1H
RES3EF_Large_6_to_7	0.3%	W2
COM4_Large_3	0.3%	S2L
COM1_Large_Mid	0.3%	S2M
COM4_Large_Mid	0.3%	S1M
IND2_Large_2_3	0.2%	S2L

(1) See Table 3-1 for the Hazus Occupancy Class definitions

(2) See Table 6-1 for Hazus Model Building Type Definitions

Table F-16: Engineers Interviewed for Seismic MBT Determination

Engineer	Firm	State
Reid Zimmerman	KPFF Consulting Engineers, Portland, OR	Oregon
Jeff Soulages	Intel Corporation, Portland, OR	Oregon
Eric McDonnell, Jennifer Eggers	Holmes Structures, Portland, OR	Oregon
Peter Somers	MKA, Seattle, WA	Washington
Terry Lundeen	Coughlin Porter Lundeen, Seattle, WA	Washington
Jerod Johnson	Reaveley Engineers + Associates, Salt Lake City, UT	Utah
Berry Welliver	BHW Engineers, LLC, Salt Lake City, UT	Utah
Dave Evans	AECOM, Anchorage, AK	Alaska
Nick Choromanski	CRW Engineers, Inc., Anchorage, AK	Alaska
Mark Anderson	R&M Consultants, Inc. Anchorage, AK	Alaska
Ian Robertson	University of Hawaii at Manoa, Honolulu, HI	Hawaii
Steve Baldridge	Baldridge & Associates Structural Engineering Inc., Honolulu, HI	Hawaii
Doug Bausch(1)	NiyamIT Inc., Kihei, Hawaii	Hawaii

(1) Provided custom Hazus damage functions for post and pier construction (see Section F.3.2.3)

Table F-17: Dominant Construction Profiles for Oregon Used to Solicit Input from Local Engineers and Resulting MBT Assignment

Construction Profile: Occupancy(1)_Size_Stories	Profile % of Statewide SF	Example Occupancy Descriptions	Model Building Type(2)
RES1_Small_1_to_3	43.4%	Single-Family Residential	W1
RES1_Medium_1_to_3	26.4%	Single-Family Residential	W1
RES3A_Small_1_to_3	0.8%	Duplex	W1
RES3A_Medium_1_to_3	1.1%	Duplex	W1
RES3BCD_Medium_1_to_3	3.5%	Apartments, Condos 3-19 Units	W2
RES3EF_Large_1_to_3	5.4%	Apartments, Condos 20-50 Units	W2
AGR1_Small_1_to_3	2.2%	Agriculture	W2
AGR1_Medium_1_to_3	1.7%	Agriculture	S3
COM3_Medium_1_to_3	0.5%	Service Stations	PC1
COM4_Medium_1_to_3	1.92%	Offices	S2L
COM4_Large_1_to_3	5.5%	Offices	S2L
COM4_Large_4_to_7	0.7%	Offices	S4M
COM4_Large_8+	0.9%	Offices	C2H
EDU1_Large_1_to_3	0.5%	Grade Schools	RM1L
GOV1_Large_1_to_3	0.6%	Government Offices	S2L

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

(2) See Table 6-1 for Hazus Model Building Type definitions

Table F-18: Dominant Construction Profiles for Washington Used to Solicit Input from Local Engineers and Resulting MBT Assignment

Construction Profile: Occupancy(1)_Size_Stories	Profile % of Statewide SF	Example Occupancy Descriptions	Model Building Type(2)
RES1_Small_1_to_3	31.8%	Single-Family Residential	W1
RES1_Medium_1_to_3	29.3%	Single-Family Residential	W1
RES3A_Small_1_to_3	1.05%	Duplex	W1
RES3A_Medium_1_to_3	1.8%	Duplex	W1
RES3BCD_Medium_1_to_3	3.1%	Apartments, Condos 3 - 19 Units	W2
RES3EF_Large_1_to_3	1.3%	Apartments, Condos 20 - 50 units	W2
RES3EF_Large_4_to_5	2.0%	Apartments, Condos 20 - 50 units	W2
RES3EF_Large_6_to_7	1.9%	Apartments, Condos 20 - 50 units	W2
RES3EF_Large_8+	1.5%	Apartments, Condos 20 - 50 Units	C2H
RES4_Large_4_to_7	0.55%	Hotels/Motels	W2
RES4_Large_8+	0.5%	Hotels/Motels	C2H
AGR1_Medium_1_to_3	0.5%	Agriculture	C2L
COM1_Medium_1	1.3%	Stores	W2
COM1_Large_1	2.3%	Stores	RM1l
COM1_Large_2_to_3	0.6%	Stores	S2L
COM2_Medium_1_to_2	0.6%	Warehouses	RM1L
COM2_Large_1_to_2	3.9%	Warehouses	PC1
COM4_Medium_1_to_3	0.7%	Offices	S2L
COM4_Large_1_to_3	1.2%	Offices	C2L
COM4_Large_4_to_7	1.3%	Offices	S2M
COM4_Large_8+	2.1%	Offices	S4H
COM7_Large_4_to_7	0.3%	Medical Offices/Clinics	S2M
COM10_Large_4_to_7	0.7%	Parking Garages	C2M
EDU1_Large_1_to_3	1.7%	Grade Schools	RM1L
IND2_Large_1	1.0%	Light Industrial	PC1

(1) See Table 3-1 for the Hazus Occupancy Class definitions

(2) See Table 6-1 for Hazus Model Building Type Definitions

Table F-19: Dominant Construction Profiles for Utah Used to Solicit Input from Local Engineers and Resulting MBT Assignment

Construction Profile: Occupancy[1]_Size_Stories	Profile % of Statewide SF	Example Occupancy Descriptions	Model Building Type[2]
RES1_Small_1_to_3	37.7%	Single-Family Residential	W1
RES1_Medium_1_to_3	36.3%	Single-Family Residential	W1
RES3A_Small_1_to_3	1.4%	Duplex	W1
RES3A_Medium_1_to_3	1.3%	Duplex	W1
RES3BCD_Medium_1_to_3	6.0%	Apartments, Condos 3-19 Units	W2
RES3EF_Small_1_to_3	0.8%	Apartments, Condos 20-50 Units	W1
RES3EF_Medium_1_to_3	1.0%	Apartments, Condos 20-50 Units	W2
RES3EF_Large_1_to_3	0.8%	Apartments, Condos 20-50 Units	W2
RES3EF_Large_4_to_5	0.5%	Apartments, Condos 20-50 Units	C2M
COM1_Medium_1	0.8%	Stores	W2
COM1_Large_1	1.3%	Stores	RM1L
COM1_Large_4_to_7	1.0%	Stores	S1M
COM2_Large_1_to_2	0.7%	Warehouses	PC1
COM4_Medium_1_to_2	2.0%	Offices	RM1L
COM4_Large_1_to_2	2.4%	Offices	S2L
IND2_Medium_1	0.5%	Light Industrial	RM1L
IND2_Large_1	1.0%	Light Industrial	RM1L

(1) See Table 3-1 for the Hazus Occupancy Class definitions

(2) See Table 6-1 for Hazus Model Building Type definitions

Table F-20: Dominant Construction Profiles for Alaska Used to Solicit Input from Local Engineers and Resulting MBT Assignment

Construction Profile: Occupancy[1]_Size_Stories	Profile % of Statewide Square Footage	Example Occupancy Descriptions	Model Building Type[2]
RES1_Small_1_to_3	49.6%	Single-Family Residential	W1
RES1_Medium_1_to_3	20.9%	Single-Family Residential	W1
RES3A_Small_1_to_3	7.7%	Duplex	W1
RES3A_Medium_1_to_3	7.7%	Duplex	W1
RES3BCD_Medium_1_to_3	3.9%	Apartments, Condos 3-19 Units	W1
COM1_Large_1	0.5%	Stores	RM1L
COM4_Medium_1_to_2	1.5%	Offices	W2
IND4_Medium_0	0.6%	Metals/Minerals Processing	S3[3]
IND4_Large_0	0.7%	Metals/Minerals Processing	S3[3]

(1) See Table 3-1 for the Hazus Occupancy Class definitions

(2) See Table 6-1 for Hazus Model Building Type definitions

(3) Local engineers had difficulty assigning a Model Building Type to this occupancy. A visual check by the in-house engineers using Google Earth revealed that many of these buildings appeared to be constructed of light steel frame, MBT S3.

Table F-21: Dominant Construction Profiles for Hawaii Used to Solicit Input from Local Engineers and Resulting MBT Assignment

Construction Profile: Occupancy(1)_Size_Stories	Profile % of Statewide SF	Example Occupancy Descriptions	Model Building Type(2)
RES1_Small_1_to_3	52.7%	Single-Family Residential	W1
RES1_Medium_1_to_3	27.0%	Single-Family Residential	W1
RES1_Large_1_to_3	0.6%	Single-Family Residential	RM1
RES3A_Small_1_to_3	0.6%	Duplex	W1
RES3A_Medium_1_to_3	0.6%	Duplex	W1
RES3BCD_Medium_1_to_3	1.0%	Apartments, Condos 3-19 Units	RM2L
RES4_Large_8+	0.9%	Hotels/Motels	C2H
COM2_Medium_1_to_3	2.5%	Warehouses	S3
COM2_Large_1_to_3	5.1%	Warehouses	PC1
COM4_Small_1_to_2	0.4%	Offices	RM1L
COM4_Medium_1_to_2	2.8%	Offices	RM1L
COM4_Large_1_to_3	4.9%	Stores	PC1(3)

(1) See Table 3-1 for the Hazus Occupancy Class definitions

(2) See Table 6-1 for Hazus Model Building Type Definitions

(3) Construction Profiles for this entry in the data base were investigated with Google Earth and found to be primarily retail occupancies

F.3.2.3 Custom Modeling of Post and Pier Houses in 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, which is more vulnerable to damage than conventional wood-frame buildings on slab foundations, as demonstrated by the 2006 Kiholo Bay Earthquake. Observed damage included “movement of piers, sliding or unseating of posts relative to piers, failure of braces and failure of other services” (FEMA, 2009b).

In a post and pier-supported house, the first floor is typically elevated by 2 to 3 feet above grade, or greater, often to accommodate sloping sites. The elevated first floor is typically constructed with wood girders and joists overlaid with plywood or wood decking. The floor framing is supported by wood posts, supported in turn on precast concrete foundation blocks (FEMA, 2012a; FEMA, 2009b).

The performance of this building type has been extensively studied, 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 in 2000 and later, which reflects code-required improvements to continuous load paths, making the structures more resistant to damage. In addition to custom capacity curves, custom fragility curves were also developed, but are identical for the two post and pier buildings types studied here.

For the current assessment, it has been assumed that post-2000 single-family dwellings (Hazus Occupancy Class RES1) of 2,000 square feet and less on the islands of Hawaii and Maui are built with improved post and pier construction. Their exposure is summarized in Table F-22.

Table F-22: Post and Pier Construction as Modeled on Hawaii and Maui

	All Post-2000 Single-Family Dwellings		Post-2000 Single-Family Dwellings – Post and Pier			
County	**Number of Buildings**	**Square Footage (MSF)**	**Number of Buildings**	**Square Footage (MSF)**	**Percent of Buildings**	**Percent of SF**
Hawaii	18,083	28.0	14,674	17.8	81%	64%
Maui	8,559	15.3	6,058	7.6	71%	50%
Total	**26,642**	**43.3**	**20,732**	**25.4**	**78%**	**59%**

Notes: MSF = million square feet

F.3.3 Limitations of the Seismic Methodology

This study was intended to measure the losses avoided by adopting the I-Codes or similar building codes, as exemplified by the I-Codes. Losses included are primarily direct losses measured by repair or replacement costs to structures, nonstructural systems, and contents. Deaths and injuries have not been monetized. Other Hazus studies (e.g., NIBS, 2018) show monetized casualty losses can be as high as 50% of direct losses. Losses due to business interruption are also not included. These losses are not considered in the current seismic study to be consistent with results for other hazards, because the methodology applied here for hurricane wind and flood do not estimate casualties or losses due to business interruption.

The losses estimated are probabilistic in the sense that there are no losses avoided until there is an earthquake, and there certainly have not been earthquakes in the last 20 years affecting all regions of the six western seismic states under study. Nevertheless, the probability of various-sized earthquake ground motions striking each building when designed under various codes was considered, along with the associated losses, and the results summed and compared.

The database of individual buildings studied comes from a CoreLogic compilation of local assessor's files, which will systematically exclude buildings not subject to property tax, such as public hospitals, fire stations, police stations, schools, and other public buildings. Code improvements that have affected design of these buildings will therefore not be measured, contributing to the underestimation of avoided losses.

There have been changes to seismic provisions in every code cycle, including all editions of the I-Codes, as well as its predecessors. The majority of these changes would be considered improvements that will reduce building damage. Minor exceptions include reductions in the local hazard level based on new seismological information that may be considered an "improvement," but results in weaker buildings and higher probable damage. In these instances, reductions in mapped hazard between the pre-I-Code code and the I-Code or similar code will produce negative results in this methodology ("negative losses avoided"). It is assumed that such reductions are scientifically justified, and will produce more efficient building designs—designs that will meet the code intent but will have lower construction cost. Changes in building construction costs or cost-benefit relationships were not considered in this study. Such studies would be aimed at improving the efficiency of seismic codes, and would depend heavily on comprehensively defining the intent of the code (i.e., target performance at each shaking level). In this study, the only change that affected all buildings was the remapping of hazard that has generally occurred every other code development cycle. Most other changes affect only one building type or material (e.g., changes in material standards) or subsets of buildings (e.g., irregular buildings or drift-controlled buildings).

This study was originally conceived as using the standard Hazus methodology to the extent possible, including the built-in group of MBTs and the built-in structural strengths; Design Levels of Pre-Code, Low Code (applies to UBC Zone 1), Moderate Code (applies to UBC Zone 2B), and High Code (applies to UBC Zone 4). The study included standard Hazus modeling of structural systems (see Table 6-1) and nonstructural systems (see Table 6-2). Changes in building vulnerability due to code changes affecting only one Model Building Type, or a small subset of buildings, was not possible for the study. Hazus incorporates seven parameters to describe the building's capacity resulting from a given seismic design, two more parameters to describe the design's response in shaking, and four fragility curves for each Design Level. Although it is theoretically possible to develop these numerical descriptions of a design considering every code change, it was beyond the scope of this study, and would be a significant task. The biggest issue related to such modeling improvements would be to identify the associated numerical improvements in performance that would guide revisions in the parameters. Such incremental improvements are, in general, not in the literature, would have to be assigned using engineering judgement, and would probably be controversial. Significant issues such as basic ductility detailing requirements were already incorporated into the original Hazus modeling parameters, so singular improvements in material standards or detailing (e.g., braced frame connections, concrete confinement) would fall into this category. However, other incremental improvements or new provisions concerning load path, detailing, inspections, redundancy, wall anchorage, and protection of non-structural systems have not been considered, resulting in an underestimation of losses avoided.

Hazus model building types, in general, were developed to recognize standard seismic resisting systems used in the United States, and described in model codes. However, since the Hazus methodology was developed, several lateral force resisting systems have been developed or refined to the extent that no Hazus Model Building Type is truly representative, including base isolation and added damping, buckling restrained braced frames, coupled shear walls, and several others. However, buildings with these systems were expected to represent a very small fraction of the total square footage in the study and were approximately modeled using existing Hazus MBTs. Similarly, Hazus groups building heights into three categories: low-rise (one to three stories), mid-rise (four to seven stories), and high-rise (eight+ stories). Although the varying periods of these classifications are considered, special design and unique systems of very tall buildings (e.g., 40+ stories) cannot be identified and are not explicitly considered.

The most significant variable in translating designs into Hazus models is the building strength—the Design Level. Due to the inclusion in the I-Codes or similar codes of hazard levels greater than the traditional Zone 4, it was necessary in this project to create two new Design Levels greater than Hazus High Code. In addition, the 97 UBC and the I-Codes adopted site soil factors that have increased the effect of soil on building strength. In this project, the design strength of each building, and therefore its Hazus Design Level, is determined considering both the mapped hazard and the site soil condition. It should also be noted that the probabilistic demands used to calculate losses also consider the effects of site soil conditions.

The seismic losses avoided estimated in this study were relatively low compared to the other hazards. The six western seismic states were chosen for the study because they represent 78.5% of the national seismic AAL. The AAL is high in this region because of large population and high seismicity. However, due to the high seismicity—both size and frequency of events—these states have adopted seismic codes for some time, in most regions for 40 to 50 years. All regions had reasonable seismic codes in place immediately prior to 2000 (with the exception of Alaska, which still has no adopted residential code outside of cities). Losses avoided are therefore only the difference between the I-Codes and similar codes and slightly older editions of seismic codes. If any regions in the West had not adopted any seismic codes before 2000, the losses avoided in that region would be substantially larger.

F.4 Supplemental Information for California Demonstration Study Results

F.4.1 Development of Final Analysis Datasets for California

The baseline parcel database of post-2000 construction developed for use in this study contained 1.39 million records for California, with 4,975 million square feet of building area. Analyses were focused on the Hazus Occupancy Classes representing the majority of exposure. In California, records for the top 16 occupancies (by building square footage) were included, representing 96.3% of records in the final GIS data set, 97.2% of total building square footage, and 97.4% of building replacement value. In addition, a handful of 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.

A summary of the California analysis data set is provided in Table F-23 by Hazus Occupancy. Residential construction makes up the majority of the California exposure. RES1 and RES3A construction (governed by the IRC) accounts for 93% of records, 62% of square footage, and

66% of building value. Multi-family construction represents an additional 6% of records, 18% of square footage, and 19% of building value.

Table F-23: Summary of Post-2000 California Data Included in the Final Analysis Dataset, by Hazus Occupancy Class

Occupancy Class[1]	Record Count	Total Building Area (SF)	Total Building Replacement Value ($M)	Total Content Replacement Value ($M)[2]
AGR1	13,318	21,324,762	$2,915	$2,915
COM1	14,309	220,518,046	$28,356	$28,356
COM2	8,270	344,681,279	$45,845	$45,845
COM4	8,466	201,940,816	$41,102	$41,102
COM7	1,422	19,805,260	$5,023	$7,534
COM8	3,714	19,841,101	$5,090	$5,090
COM10	1,218	38,373,738	$3,472	$1,736
IND2	4,924	98,423,000	$13,377	$20,066
RES1	1,205,802	2,927,912,175	$588,826	$294,413
RES3A	33,909	89,263,872	$12,476	$6,238
RES3B	15,734	70,465,054	$8,698	$4,349
RES3C	12,946	98,438,924	$22,529	$11,264
RES3D	5,683	67,891,942	$14,522	$7,261
RES3E	2,960	75,013,084	$16,281	$8,141
RES3F	3,369	507,898,959	$98,928	$49,464
RES4	1,060	33,033,763	$6,869	$3,434
Total	**1,337,104**	**4,834,825,775**	**$914,309**	**$537,208**

(1) See Table 3-1 for the Hazus Occupancy Class definitions

(2) 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).

Table F-24 provides a summary of the California analysis dataset by county. As the table shows, several of the Southern California counties are the largest contributors to statewide exposure, including San Bernardino (17% of the post-2000 construction by square footage), Los Angeles (14%), Riverside (11%), and San Diego (8%). In Northern California, Sacramento is the only county that accounts for more than 5% of the state's square footage exposure.

Exposure may also be summarized by county analysis priority (see Section F.2.4). The 27 high analysis priority counties represent 86% of records, 90% of building square footage, and 91% of building value. The 14 medium-priority counties represent 12% of records, 8% of square footage, and 8% of building value.

Table F-24: Summary of Post-2000 California Data Included in the Final Analysis Dataset, by County

County	Record Count	Total Building Area (sq. ft.)	Total Building Replacement Value ($M)	Total Content Replacement Value ($M)
Alameda	27,061	153,271,462	$32,280	$20,605
Alpine	191	629,784	$119	$62
Amador	3,253	6,254,702	$1,043	$610
Butte	11,801	27,246,891	$4,725	$2,903
Calaveras	5,621	10,565,092	$1,867	$981
Colusa	1,425	2,575,730	$434	$266
Contra Costa	49,707	162,286,066	$35,294	$19,421
Del Norte(1)				
El Dorado	16,586	45,130,730	$9,576	$4,978
Fresno	56,884	158,857,474	$28,877	$18,053
Glenn	1,621	2,487,861	$395	$277
Humboldt(1)				
Imperial(1)				
Inyo	335	792,665	$127	$82
Kern	63,122	151,212,457	$26,393	$15,748
Kings	8,732	17,619,900	$2,961	$1,668
Lake	4,420	7,289,805	$1,236	$645
Lassen	1,780	2,629,269	$475	$294
Los Angeles	117,380	665,511,456	$116,201	$74,583
Madera	11,012	21,039,070	$3,562	$2,051
Marin	3,987	14,512,139	$3,319	$1,930
Mariposa(1)				
Mendocino(1)				
Merced	18,059	35,078,319	$6,026	$3,128
Modoc	600	663,612	$125	$97
Mono	1,075	3,282,185	$517	$279
Monterey	11,421	28,210,488	$5,514	$3,138
Napa	6,078	20,621,075	$3,974	$2,730
Nevada	7,022	19,704,964	$3,645	$2,050
Orange	42,142	134,255,779	$29,186	$14,595
Placer	49,071	146,407,139	$29,424	$16,802
Plumas	1,523	3,113,678	$524	$277
Riverside	211,636	544,229,640	$104,401	$52,256
Sacramento	82,765	245,760,922	$47,615	$28,209
San Benito	1,056	2,512,078	$514	$269
San Bernardino	107,569	833,555,155	$145,911	$91,008
San Diego	111,085	395,950,547	$73,574	$42,541
San Francisco	2,419	56,780,790	$12,550	$7,538
San Joaquin	52,150	122,445,477	$24,949	$12,572

Table F-24: Summary of Post-2000 California Data Included in the Final Analysis Dataset, by County (cont.)

County	Record Count	Total Building Area (sq. ft.)	Total Building Replacement Value ($M)	Total Content Replacement Value ($M)
San Luis Obispo	17,613	38,492,860	$6,992	$3,737
San Mateo	8,470	44,135,600	$10,392	$6,615
Santa Barbara	10,456	24,103,648	$4,512	$2,279
Santa Clara	36,501	202,630,568	$44,714	$28,440
Santa Cruz	5,455	13,795,411	$2,743	$1,542
Shasta	10,608	21,088,023	$3,711	$2,175
Sierra	316	413,963	$74	$40
Siskiyou	2,104	3,191,847	$494	$247
Solano	20,339	65,617,975	$13,600	$7,846
Sonoma	18,906	56,544,682	$11,310	$7,147
Stanislaus	31,784	88,477,828	$15,798	$9,435
Sutter	6,189	14,854,110	$2,673	$1,492
Tehama	5,283	7,469,586	$1,230	$687
Trinity(1)				
Tulare	26,597	67,182,606	$10,937	$6,533
Tuolumne	3,612	6,634,105	$1,093	$586
Ventura	22,981	86,921,125	$16,879	$10,200
Yolo	12,454	36,786,070	$7,221	$4,175
Yuba	6,847	14,001,365	$2,601	$1,389
Total	**1,337,104**	**4,834,825,775**	**$914,309**	**$537,208**

(1) Counties not represented in the source CoreLogic database

F.4.2 California Average Annual Losses Avoided

Table F-25 provides a summary of estimated AAL for the pre-I-Code and I-Code representations of the inventory, as well as a calculation of the estimated losses avoided for all modeled buildings in California by county. As shown in the table, the total AAL (building and contents losses only) for post-2000 construction designed under the pre-I-Code codes is $538.0 million, versus $496.5 million for I-Code design, resulting in a $41.5 million (8%) loss avoided.

The losses can also be presented in terms of an Annualized Earthquake Loss Ratio (AELR), expressing annualized loss as a fraction of the building inventory replacement value. Accordingly, the pre-I-Code AELR is 588.4 ($/$M exposed), and the I-Code AELR is 543.1 ($/$M exposed). These AELRs compared reasonably well with the AELR reported for California from the FEMA AAL study (FEMA, 2017), which totaled 971.5 ($/$M exposed). Because the post-2000 inventory is the more modern part of the exposure, and the losses do not include inventory or income losses, the current study's AELR was expected to be less than that of the full inventory from the prior study.

As can be seen in Table F-25, the same Southern California counties that are the largest contributors to statewide exposure are also the largest contributors to losses and losses avoided, including Los Angeles (26.3% of losses avoided), Riverside (14.6% of losses avoided), and San Bernardino (13.9% of losses avoided). Several urban high-hazard Bay Area counties are also significant contributors to losses avoided, including Alameda (9.6%), Santa Clara (7.6%), Contra Costa (4.3%), and San Mateo Counties (3.4%).

Average annual losses per building are largest in San Francisco (approximately $3,600 per building for the pre-I-Code design), followed by several other Bay Area Counties—Alameda, Santa Clara, and San Mateo. As expected, AAL per building is smaller in the lower hazard counties; for example, Fresno County has a pre-I-Code AAL per building of approximately $100 per building. As shown in the table, however, San Francisco's AALA is small, primarily because it has few post-2000 buildings, and although there were modest increases in code hazard levels over time, a large proportion of these structures (88%) are assigned to the same Hazus Design Level under both the pre-I-Code and I-Code design.

For the California demonstration study, inventory and income losses were also calculated. Although these losses may be estimated using the Hazus Earthquake Advanced Engineering Building Module (AEBM) methods, similar computations are not possible in the flood or hurricane wind methods applied here. Accordingly, for consistency across the various hazards, inventory and income loss results are not included in the tables provided below, but are provided in Section F.4.3. Estimated inventory losses for California were very small, with statewide totals that were just 1% of those for building damage. Income losses were slightly larger, reaching 12 to 13% of building damage.

F.4.2.1 Negative Losses Avoided

As can be seen in Table F-25, several counties (e.g., Kern, Placer, El Dorado, San Diego) produce higher AALs for the I-Code analysis than for the pre-I-Code analysis, leading to negative losses avoided. Negative losses avoided are generally 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 historical seismicity plus some amount of judgement and political influence. For example, most of the Central Valley of California 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 hazard 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 scientifically (for the 2000 IBC) indicated that the old zones were conceptually correct, but that boundaries, in general, were not accurate. In the 2000 IBC, while many sites within a given zone were required to have building strengths nearly the same as the previous UBC, some required more strength, and others less. If there were more sites in a county that 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 can only be seen in UBC Zone 3 or less because in Zone 4, near active faults, the contour values of hazard generally increased.

The only coastal county in California encompassing the fault zones that yielded a negative loss avoided was San Diego. The faults generating the seismic hazard in San Diego County run generally from the southeastern corner northwesterly along the boundary of the heavily populated regions of the county. Accordingly, most parcels in San Diego County are in hazard contours that generally decrease moving away from the fault. Of the 619 census tracts in San Diego County, 469 had a reduced hazard demand under the 2006 IBC (relative to the zone-based 1994 or 1997 UBC) sufficient to lower the Hazus Design Level from High Code (for the previous Zone 4) to Moderate Code (appropriate for the contours of hazard in the IBC).

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 from High Code to Moderate 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 occur, but creating smooth transitions in building strengths in Hazus would be complex and beyond the scope of this study.

Table F-25: Summary of California Pre-I-Code and I-Code Average Annual Losses and Losses Avoided for Post-2000 Buildings by County

	Pre-I-Code AAL ($1,000)			I-Code AAL($1,000)			Losses Avoided ($1,000)		
County	Bldg	Cont	Total	Bldg	Cont	Total	Bldg	Cont	Total
Alameda	$24,305	$10,553	$34,858	$21,802	$9,074	$30,876	$2,504	$1,479	$3,983
Alpine	$40	$14	$54	$39	$14	$53	$1	$0	$1
Amador	$46	$18	$63	$48	$19	$67	−$3	–$1	−$4
Butte	$728	$318	$1,047	$639	$285	$924	$90	$33	$123
Calaveras	$78	$28	$106	$80	$29	$109	−$2	–$1	−$3
Colusa	$110	$47	$157	$	$43	$142	$11	$4	$15
Contra Costa	$18,873	$7,761	$26,635	$17,713	$7,140	$24,852	$1,161	$622	$1,782
Del Norte(1)									
El Dorado	$604	$227	$831	$613	$232	$845	−$9	–$5	−$14
Fresno	$3,797	$1,664	$5,461	$3,493	$1,560	$5,054	$304	$104	$408
Glenn	$95	$44	$139	$84	$40	$124	$11	$3	$15
Humboldt(1)									
Imperial(1)									
Inyo	$39	$19	$58	$32	$14	$46	$6	$5	$12
Kern	$6,181	$2,773	$8,953	$6,236	$2,708	$8,945	−$56	$65	$9
Kings	$613	$257	$870	$579	$246	8$26	$34	$10	$44
Lake	$598	$238	$836	$537	$208	$746	$60	$30	$90
Lassen	$96	$41	$137	$93	$40	$133	$3	$1	$4
Los Angeles	$64,422	$28,278	$92,700	$57,837	$23,970	$81,807	$6,584	$4,309	$10,893
Madera	$396	$166	$563	$369	$155	$524	$28	$11	$39
Marin	$1,604	$655	$2,259	$1,562	$639	$2,201	$42	$16	$58
Mariposa(1)									
Mendocino(1)									
Merced	$1,200	$471	$1,671	$1,161	$459	$1,620	$39	$12	$50
Modoc	$13	$7	$20	$11	$6	$17	$2	$1	$3
Mono	$192	$76	$267	$161	$57	$219	$30	$18	$49
Monterey	$2,468	$1,066	$3,533	$2,328	$991	$3,320	$139	$74	$214
Napa	$2,576	$1,240	$3,817	$2,256	$1,000	$3,256	$320	$241	$561
Nevada	$684	$254	$938	$616	$246	$863	$68	$8	$75
Orange	$8,310	$3,118	$11,428	$8,015	$2,902	$10,917	$294	$216	$511
Placer	$2,402	$966	$3,369	$2,449	$976	$3,425	−$46	–$10	−$56
Plumas	$181	$67	$248	$181	$67	$248	$0	$0	$0
Riverside	$48,241	$18,222	$66,463	$44,173	$16,230	$60,403	$4,068	$1,992	$6,060
Sacramento	$5,872	$2,416	$8,288	$5,394	$2,239	$7,633	$478	$177	$655
San Benito	$641	$242	$883	$545	$191	$736	$96	$51	$147
San Bernardino	$84,564	$38,799	$123,364	$81,065	$36,551	$117,616	$3,500	$2,248	$5,748
San Diego	$12,091	$4,990	$17,081	$12,305	$4,990	$17,295	−$214	0	–$214
San Francisco	$6,412	$2,316	$8,728	$6,289	$2,235	$8,524	$124	$81	$204
San Joaquin	$929	$2,318	$8,247	$5,743	$2,253	$7,996	$186	$65	$252

Table F-25: Summary of California Pre-I-Code and I-Code Average Annual Losses and Losses Avoided for Post-2000 Buildings by County (cont.)

	Pre-I-Code AAL ($1,000)			**I-Code AAL($1,000)**			**Losses Avoided ($1,000)**		
County	**Bldg**	**Cont**	**Total**	**Bldg**	**Cont**	**Total**	**Bldg**	**Cont**	**Total**
San Luis Obispo	$1,517	$609	$2,127	$1,422	$528	$1,950	$95	$82	$177
San Mateo	$7,211	$2,728	$9,939	$6,322	$2,192	$8,514	$889	$535	$1,424
Santa Barbara	$1,368	$499	$1,867	$1,175	$387	$1,563	$192	$112	$304
Santa Clara	$33,083	$13,610	$46,693	$31,055	$12,480	$43,535	$2,028	$1,130	$3,158
Santa Cruz	$1,770	$731	$2,501	$1,631	$670	$2,302	$139	$61	$200
Shasta	$1,006	$421	$1,426	$919	$390	$1,309	$86	$31	$117
Sierra	$21	$8	$29	$21	$8	$29	$0	$0	$0
Siskiyou	$37	$14	$51	$37	$14	$51	$0	$0	$0
Solano	$5,998	$2,539	$8,536	$5,578	$2,282	$7,860	$419	$256	$676
Sonoma	$7,294	$3,198	$10,492	$6,411	$2,690	$9,101	$883	$508	$1,391
Stanislaus	$3,029	$1,293	$4,322	$2,732	$1,183	$3,915	$297	$110	$407
Sutter	$292	$118	$410	$275	$111	$385	$18	$7	$25
Tehama	$277	$114	$390	$269	$112	$381	$8	$2	$10
Trinity(1)									
Tulare	$1,240	$534	$1,773	$1,126	$490	$1,617	$113	$44	$157
Tuolumne	$30	$11	$41	$32	$12	$43	−$2	–$1	–$3
Ventura	$7,517	$3,267	$10,785	$6,638	$2,653	$9,291	$879	$614	$1,494
Yolo	$1,546	$639	$2,186	$1,393	$593	$1,986	$154	$47	$200
Yuba	$237	$94	$331	$230	$91	$321	$7	$3	$10
Total	$**377,873**	$**160,098**	$**537,972**	$**351,817**	$**144,696**	$**496,513**	$**26,057**	**$15,402**	**$41,459**

(1) Counties not represented in the source CoreLogic database

Bldg = total building damage: structural, acceleration-sensitive nonstructural, and drift-sensitive nonstructural damage
Cont = contents losses
Total = Bldg + Cont losses

F.4.2.2 Losses by Analysis Priority

Losses can also be summarized by county analysis priority (see Section F.2.4). The 27 high analysis priority counties account for approximately 97% of pre-I-Code and I-Code losses and losses avoided (versus 91% of dollar exposure value), while the 14 medium analysis priority counties represent 2 to 3% of pre-I-Code and I-Code losses and losses avoided (versus 8% of dollar exposure value). This supports the contention that analyses can focus on high-priority or high- and medium-priority counties and capture the majority of the losses and losses avoided.

F.4.2.3 Inclusion of all Buildings versus Only Those Producing Losses Avoided

The current demonstration study for California included all post-2000 construction records in the Hazus analyses; an alternative, smaller analysis would have included only those buildings with potential to produce losses avoided (i.e., with a change in Hazus Design Level) in the Hazus analyses. Including all buildings captures the full AAL expected for all post-2000 construction, and expresses the AAL avoided as a percentage of the full pre-I-Code AAL (8%). However, 71% of the building records (71% of building square footage and 71% of building value) do not contribute to the losses avoided. That is, 71% of the records in the California analysis database have the same Design Level under pre-I-Code and I-Code design, and therefore have no losses avoided. The 29% of records that have a change in Design Level and produce losses avoided produced 36% of total pre-I-Code AAL, 30% of I-Code AAL, and 100% of the losses avoided. For these records, the losses avoided represent 22% of the pre-I-Code AAL.

To execute the analysis of more than 1.3 million records, multiple Hazus analyses, each containing one or more counties, were required. A total of 32 Hazus study regions were created (16 for pre-I-Code design and 16 for I-Code design), with AEBM databases ranging from 29,000 records to 135,000 records, with associated run-times of 2.5 hours to more than 30 hours. Because each analysis was effectively run twice (once for pre-I-Code design and once for I-Code design), the total Hazus run-time for all analyses exceeded 440 hours. The total run-time would have been significantly reduced if the analysis had been limited to the 29% of records that produced the losses avoided. Nevertheless, for the analysis of the remaining five seismic states, the decision was made to execute the full analysis (i.e., to include those records with no change in Design Level) to estimate the full AAL, and losses avoided as a percentage of full AAL, despite the lengthy run-times required.

F.4.2.4 Losses by Occupancy Class

Table F-26 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 in California by Hazus Occupancy Class. Residential construction governed by the IRC, Hazus Occupancy Classes RES1 and RES3A (one- and two-family residential structures), accounts for 53% of both the pre-I-Code and Code losses and 59% of the losses avoided. Hazus Occupancy Classes RES3B and RES3F (multi-family residential structures) represent 21% of the pre-I-Code losses, 22% of the I-Code losses, and 13% of the losses avoided. Together, these residential structures represent 74% of the losses and 73% of the losses avoided.

Table F-26: Summary of California Pre-I-Code and I-Code Average Annual Losses and Losses Avoided for Post-2000 Buildings by Hazus Occupancy Class

Occupancy Class[1]	Pre-I-Code AAL ($1,000)			I-Code AAL ($1,000)			Losses Avoided ($1,000)		
	Bldg	**Cont**	**Total**	**Bldg**	**Cont**	**Total**	**Bldg**	**Cont**	**Total**
AGR1	$1,351	$668	$2,018	$1,205	$607	$1,812	$146	$61	$207
COM1	$11,818	$8,133	$19,951	$10,827	$7,273	$18,100	$990	$860	$1,850
COM10	$2,325	$639	$2,964	$2,052	$566	$2,618	$273	$73	$346
COM2	$34,496	$20,637	$55,133	$32,135	$18,963	$51,098	$2,361	$1,674	$4,034
COM4	$25,342	$12,307	$37,649	$23,698	$11,100	$34,798	$1,644	$1,207	$2,851
COM7	$2,220	$1,584	$3,804	$2,073	$1,454	$3,527	$147	$130	$277
COM8	$2,467	$1,498	$3,966	$2,302	$1,375	$3,676	$166	$124	$289
IND2	$ 9,311	$7,092	$16,403	$8,410	$6,316	$14,726	$901	$776	$1,677
RES1	$202,713	$76,294	$279,007	$187,234	$67,810	$255,044	$15,479	$8,484	$23,962
RES3A	$5,351	$1,895	$7,246	$4,900	$1,653	$6,553	$452	$242	$694
RES3B	$3,349	$1,191	$4,540	$3,102	$1,072	$4,174	$247	$119	$366
RES3C	$9,819	$3,498	$13,317	$9,059	$3,142	$12,201	$760	$356	$1,116
RES3D	$6,454	$2,299	$8,752	$6,000	$2,072	$8,071	$454	$227	$681
RES3E	$ 8,098	$2,913	$11,012	$7,598	$2,631	$10,229	$501	$282	$782
RES3F	$49,968	$18,480	$68,448	$48,738	$17,846	$66,583	$1,231	$634	$1,864
RES4	$2,791	$970	$3,761	$2,484	$817	$3,301	$307	$153	$460
Total	**$377,873**	**$160,098**	**$537,972**	**$351,817**	**$144,696**	**$496,513**	**$26,057**	**$15,402**	**$41,459**

(1) See Table 3.1 for the Hazus Occupancy Class definitions

Bldg = total building damage: structural, acceleration-sensitive nonstructural, and drift-sensitive nonstructural damage
Cont = contents losses
Total = Bldg + Cont losses

F.4.3 California Inventory and Business Interruption Losses by County and Occupancy

As noted in the previous section, for the California demonstration study, inventory and income losses were included in the calculations. Although these losses may be estimated using the Hazus Earthquake AEBM methods, similar computations are not possible in the flood or hurricane wind methods applied in this project. Accordingly, for consistency across the various hazards, inventory and income loss results are not included in the summary tables provided in the main BCS Study report, but are provided here for California only. As shown in Table F-27 (by County) and Table F-30 (by Occupancy), estimated inventory losses for California were very small, with statewide totals that were just 1% of those for building damage. Income losses were slightly larger, reaching 12 to 13% of building damage.

Table F-27: Summary of California Pre-I-Code and I-Code Average Annual Losses and Losses Avoided for Post-2000 Buildings by County, including Inventory and Business Interruption Losses

	Pre-I-Code AAL ($1,000)				I-Code AAL ($1,000)				Losses Avoided ($1,000)			
County	**Bldg**	**C&I**	**BI**	**Total**	**Bldg**	**C&I**	**BI**	**Total**	**Bldg**	**C&I**	**BI**	**Total**
Alameda	$24,305	$10,709	$3,380	$38,394	$21,802	$9,211	$2,847	$33,860	$2,504	$1,498	$532	$4,533
Alpine	$40	$14	$5	$60	$39	$14	$5	$58	$1	$0	$0	$2
Amador	$46	$18	$5	$68	$48	$19	$5	$72	−$3	−$1	$0	−$4
Butte	$728	$323	$104	$1,155	$639	$289	$77	$1,004	$90	$35	$27	$151
Calaveras	$78	$28	$6	$112	$80	$29	$6	$115	−$2	−$1	$0	−$3
Colusa	$110	$48	$15	$172	$99	$44	$12	$154	$11	$4	$3	$18
Contra Costa	$18,873	$7,818	$1,659	$28,351	$17,713	$7,194	$1,467	$26,373	$1,161	$625	$193	$1,978
Del Norte(1)												
El Dorado	$604	$228	$60	$892	$613	$233	$58	$904	−$9	−$5	$2	−$12
Fresno	$3,797	$1,693	$672	$6,163	$3,493	$1,584	$508	$5,585	$304	$110	$164	$577
Glenn	$95	$45	$21	$161	$84	$41	$15	$140	$11	$4	$5	$20
Humboldt(1)												
Imperial(1)												
Inyo	$39	$20	$7	$66	$32	$14	$5	$52	$6	$5	$2	$14
Kern	$6,181	$2,794	$830	$9,805	$6,236	$2,732	$915	$9,883	−$56	$63	−$85	−$78
Kings	$613	$260	$79	$952	$579	$249	$68	$897	$34	$11	$10	$55
Lake	$598	$239	$65	$901	$537	$209	$52	$799	$60	$30	$12	$102
Lassen	$96	41	$17	$154	$93	$40	$14	$147	$3	$1	$3	$7
Los Angeles	$64,422	$28,845	$10,199	$103,466	$57,837	$24,468	$8,903	$91,208	$6,584	$4,378	$1,297	$12,258
Madera	$396	$169	$47	$612	$369	$157	$38	$564	$28	$12	$9	$48
Marin	$1,604		$171	$2,431	$1,562	$640	$162	$2,364	$42	$16	$9	$67
Mariposa(1)												
Mendocino(1)												
Merced	$1,200	$474	$121	$1,795	$1,161	$462	$115	$1,738	$39	$12	$6	$57
Modoc	$13	$7	$7	$27	$11	$6	$3	$20	$2	$1	$3	$7
Mono	$192	$76	$16	$284	$161	$58	$13	$232	$30	$19	$3	$52

Table F-28: Summary of California Pre-I-Code and I-Code Average Annual Losses and Losses Avoided for Post-2000 Buildings by County, including Inventory and Business Interruption Losses (cont.)

	Pre-I-Code AAL ($1,000)				I-Code AAL ($1,000)				Losses Avoided ($1,000)			
County	**Bldg**	**C&I**	**BI**	**Total**	**Bldg**	**C&I**	**BI**	**Total**	**Bldg**	**C&I**	**BI**	**Total**
Monterey	$2,468	$1,073	$284	$3,825	$2,328	$999	$258	$3,586	$139	$74	$25	$239
Napa	$2,576	$1,262	$268	$4,106	$2,256	$1,017	$224	$3,497	$320	$245	$43	$609
Nevada	$684	$255	$86	$1,025	$616	$247	$68	$931	$68	$8	$18	$93
Orange	$8,310	$3,118	$534	$11,961	$8,015	$2,902	$495	$11,412	$294	$216	$39	$549
Placer	$2,402	$975	$324	$3,701	$2,449	$983	$301	$3,733	−$46	−$9	$23	−$32
Plumas	$181	$67	$24	$272	$181	$67	$24	$272	$0	$0	$0	$0
Riverside	$48,241	$18,225	$4,083	$70,549	$44,173	$16,232	$3,371	$63,776	$4,068	$1,993	$712	$6,772
Sacramento	$5,872	$2,442	$1,043	$9,357	$5,394	$2,259	$798	$8,451	$478	$183	$245	$906
San Benito	$641	$243	$56	$941	$545	$192	$42	$780	$96	$51	$14	$161
San Bernardino	$84,564	$39,631	$10,680	$134,875	$81,065	$37,338	$9,970	$128,372	$3,500	$2,294	$710	$,6503
San Diego	$12,091	$5,053	$1311	$18,455	$12,305	$5,053	$1,435	$18,794	−$214	−$1	−$124	$−339
San Francisco	$6,412	$2,321	$1,120	$9,854	$6,289	$2,240	$1,077	$9,606	$124	$81	$43	$248
San Joaquin	$5,929	$2,321	$506	$8,755	$5,743	$2,255	$474	$8,472	$186	$66	$32	$284
San Luis Obispo	$1,517	$612	$157	$2,287	$1,422	$530	$151	$2,103	$95	$82	$6	$183
San Mateo	$7,211	$2,740	$1,508	$11,459	$6,322	$2,203	$1,242	$9,767	$889	$537	$266	$1,692
Santa Barbara	$1,368	$500	$111	$1,979	$1,175	$388	$84	$1,648	$192	$112	$27	$331
Santa Clara	$33,083	$13,690	$5,155	$51,928	$31,055	$12,556	$4,804	$48,416	$2,028	$1,134	$351	$3,513
Santa Cruz	$1,770	$738	$174	$2,682	$1,631	$677	$151	$2,459	$139	$61	$22	$222
Shasta	$1,006	$424	$222	$1,651	$919	$392	$174	$1,486	$86	$32	$47	$165
Sierra	$21	$9	$2	$32	$21	$9	$2	$32	$0	$0	$0	$0
Siskiyou	$37	$14	$4	$54	$37	$14	$4	$54	$0	$0	$0	$0
Solano	$5,998	$2,568	$587	$9,153	$5,578	$2,310	$512	$8,400	$419	$258	$75	$753
Sonoma	$7,294	$3,253	$893	$11,440	$6,411	$2,739	$739	$9,889	$883	$515	$154	$1,551
Stanislaus	$3,029	$1,315	$518	$4,862	$2,732	$1,200	$389	$4,321	297	$116	$129	$541
Sutter	$292	$119	$52	$463	$275	$111	$40	$426	$18	$7	$12	$37
Tehama	$277	$115	$39	$431	$269	$113	$35	$417	$8	$2	$4	$14

Table F-29: Summary of California Pre-I-Code and I-Code Average Annual Losses and Losses Avoided for Post-2000 Buildings by County, including Inventory and Business Interruption Losses (cont.)

	Pre-I-Code AAL ($1,000)				I-Code AAL ($1,000)				Losses Avoided ($1,000)			
County	**Bldg**	**C&I**	**BI**	**Total**	**Bldg**	**C&I**	**BI**	**Total**	**Bldg**	**C&I**	**BI**	**Total**
Trinity(1)												
Tulare	$1,240	$543	$206	$1,989	$1,126	$497	$150	$1,774	$113	$46	$56	$215
Tuolumne	$30	$11	$2	$43	$32	$12	$3	$46	−$2	−$1	$0	−$3
Ventura	$7,517	$3,313	$748	$11,578	$6,638	$2,689	$622	$9,949	$879	$624	$126	$1,630
Yolo	$1,546	$648	$232	$2,426	$1,393	$600	$169	$2,162	$154	$49	$63	$265
Yuba	$237	$95	$25	$357	$230	$92	$21	$342	$7	$3	$5	$15
Total	**$377,873**	**$162,200**	**$48,438**	**$588,511**	**$351,817**	**$146,607**	**$43,120**	**$541,543**	**$26,057**	**$15,593**	**$5,318**	**$46,968**

(1) Counties not represented in the source CoreLogic database

Bldg = total building damage: structural, accelerations-sensitive non-structural, and drift sensitive non-structural damage
C & I = contents and inventory losses
BI = business interruption losses: relocation, lost rent, income losses, and wage losses
Total = Bldg + C&I + BI losses

Table F-30: Summary of California Pre-I-Code and I-Code Average Annual Losses and Losses Avoided by Hazus Occupancy Class, Including Inventory and Business Interruption Losses

	Pre-I-Code AAL ($1,000)				I-Code AAL ($1,000)				Losses Avoided ($1,000)			
Occupancy Class(1)	**Bldg**	**C&I**	**BI**	**Total**	**Bldg**	**C&I**	**BI**	**Total**	**Bldg**	**C&I**	**BI**	**Total**
AGR1	$1,351	$668	$97	$2,175	$1,205	$607	$85	$1,951	$146	$61	$11	$224
COM1	$11,818	$8,133	$3,256	$23,664	$10,827	$7,273	$2,940	$21,449	$990	$860	$316	$2,214
COM10	$2,325	$639	$115	$3,079	$2,052	$566	$101	$2,719	$273	$73	$14	$360
COM2	$34,496	$20,637	$6,620	$63,011	$32,135	$18,963	$6,121	$58,376	$2,361	$1,674	$499	$4,635
COM4	$25,342	$12,307	$9,328	$46,977	$23,698	$11,100	$8,467	$43,265	$1,644	$1,207	$861	$3,712
COM7	$2,220	$1,584	$2,770	$6,575	$2,073	$1,454	$2,556	$6,084	$147	$130	$214	$491
COM8	$2,467	$1,498	$2,168	$6,134	$2,302	$1,375	$1,967	$5,643	$166	$124	$201	$491
IND2	$9,311	$7,092	$1,114	$17,843	$8,410	$6,316	$1,029	$16,045	$901	$776	$85	$1,798
RES1	$202,713	$76,294	$16,070	$295,077	$187,234	$67,810	$13,633	$268,677	$15,479	$8,484	$2,438	$26,400
RES3A	$5,351	$1,895	$467	$7,713	$4,900	$1,653	$403	$6,956	$452	$242	$64	$758
RES3B	$3,349	$1,191	$316	$4,856	$3,102	$1,072	$277	$4,451	$247	$119	$39	$405
RES3C	$9,819	$3,498	$501	$13,819	$9,059	$3,142	$436	$12,637	$760	$356	$66	$1,182
RES3D	$6,454	$2,299	$365	$9,118	$6,000	$2,072	$324	$8,395	$454	$227	$42	$722
RES3E	$8,098	$2,913	$441	$11,453	$7,598	$2,631	$402	$10,631	$501	$282	$39	$822
RES3F	$49,968	$18,480	$2,997	$71,445	$48,738	$17,846	$2,871	$69,455	$1,231	$634	$126	$1,990
RES4	$2,791	$970	$1,812	$5,573	$2,484	$817	$1,509	$4,809	$307	$153	$303	$763
Total	**$377,873**	**$160,098**	**$48,438**	**$588,511**	**$351,817**	**$144,696**	**$43,120**	**$541,543**	**$26,057**	**$15,402**	**$5,318**	**$46,968**

(1) See Table 3-1 for the Hazus Occupancy Class definitions

Bldg = total building damage: structural, accelerations-sensitive non-structural and drift sensitive non-structural damage

C & I = contents and inventory losses

BI = business interruption losses: relocation, lost rent, income losses, and wage losses

Total = Bldg + C&I + BI losses

F.5 Data Development for the New Madrid Seismic Zone (NMSZ)

In anticipation of executing a similarly detailed losses avoided analysis for the New Madrid Seismic Zone (NMSZ), several tasks have been undertaken to begin the development process for a variety of datasets, including:

- Applying the County prioritization methodology to the eight NMSZ states (Alabama, Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee) to reduce the scope of the required analyses.
- Developing GIS layers of NEHRP soils data by Census Tract.
- Assembling code adoption history for the high- and medium-priority counties identified in Task 1, using available published documents and searches of building code agency websites, and leveraging available BCEGS data. It should be noted that several of the NMSZ states do not have statewide building codes; therefore, in the high- and medium-priority counties within those states, the Project Team relied on whatever code history is available on-line or in published documents.

F.5.1 NMSZ States – County Analysis Prioritization

An analysis prioritization exercise similar to the one conducted for the western states was executed for the eight NMSZ states, based on seismic hazard-weighted population. There were two differences in the prioritization approach for the NMSZ. First, because of the generally lower levels of seismic hazard and population dispersion, the hazard-weighted population Priority thresholds were defined proportionally lower; each County was classified as High (25,000+), Medium (5,000 – 25,000), or Low (<5,000) Analysis Priority, based on the aggregate hazard-weighted population.

Second, because of the broad geographic extent of the area, and the existence of several extremely high population exposure counties in areas of low (but non-zero) hazard, the initial prioritization included some anomalous results. For example, Cook County, Illinois, with more than 5 million in population, was categorized as High priority, despite it being well beyond the area of highest seismic hazard. Accordingly, an additional prioritization step was included in the analysis: counties with an AELR from the 2017 FEMA National AAL study (FEMA, 2017) below 35 $/$M exposed were excluded from the prioritization. For reference, Cook County has an AELR below 14, while the average county AELR for the more seismically active states of Tennessee and Arkansas are 220 and 188, respectively. As a test, the same AELR criteria were retrospectively applied to the six western seismic states; just four counties that had been previously categorized as Low Priority (two in Alaska and two in Utah) would be identified for exclusion. The resulting classification of counties is shown in Figure F-15 and summarized in Table F-31.

Table F-31: County Analysis Prioritization Results for the Eight New Madrid Seismic Zone States

	Counties (count)					County Population (million)				Total Population (million)
State	High Priority	Medium Priority	Low Priority	Excluded	Total	High Priority	Medium Priority	Low Priority	Excluded	
AL	4	16	8	39	67	1.27	1.08	0.13	2.30	4.78
AR	9	17	24	25	75	0.90	0.47	0.36	1.19	2.92
IL	5	31	21	45	102	0.34	1.61	0.29	10.58	12.83
IN	3	17	12	60	92	0.46	0.80	0.48	4.75	6.48
KY	4	22	18	76	120	0.91	0.83	0.29	2.31	4.34
MO	13	17	18	67	115	0.81	0.58	1.55	3.05	5.99
MS	1	19	23	39	82	0.16	0.70	0.34	1.76	2.97
TN	21	46	20	8	95	3.95	1.94	0.30	0.16	6.35
Total	**60**	**185**	**144**	**359**	**748**	**8.80**	**8.01**	**3.74**	**26.10**	**46.65**
%	**8%**	**25%**	**19%**	**48%**		**19%**	**17%**	**8%**	**56%**	

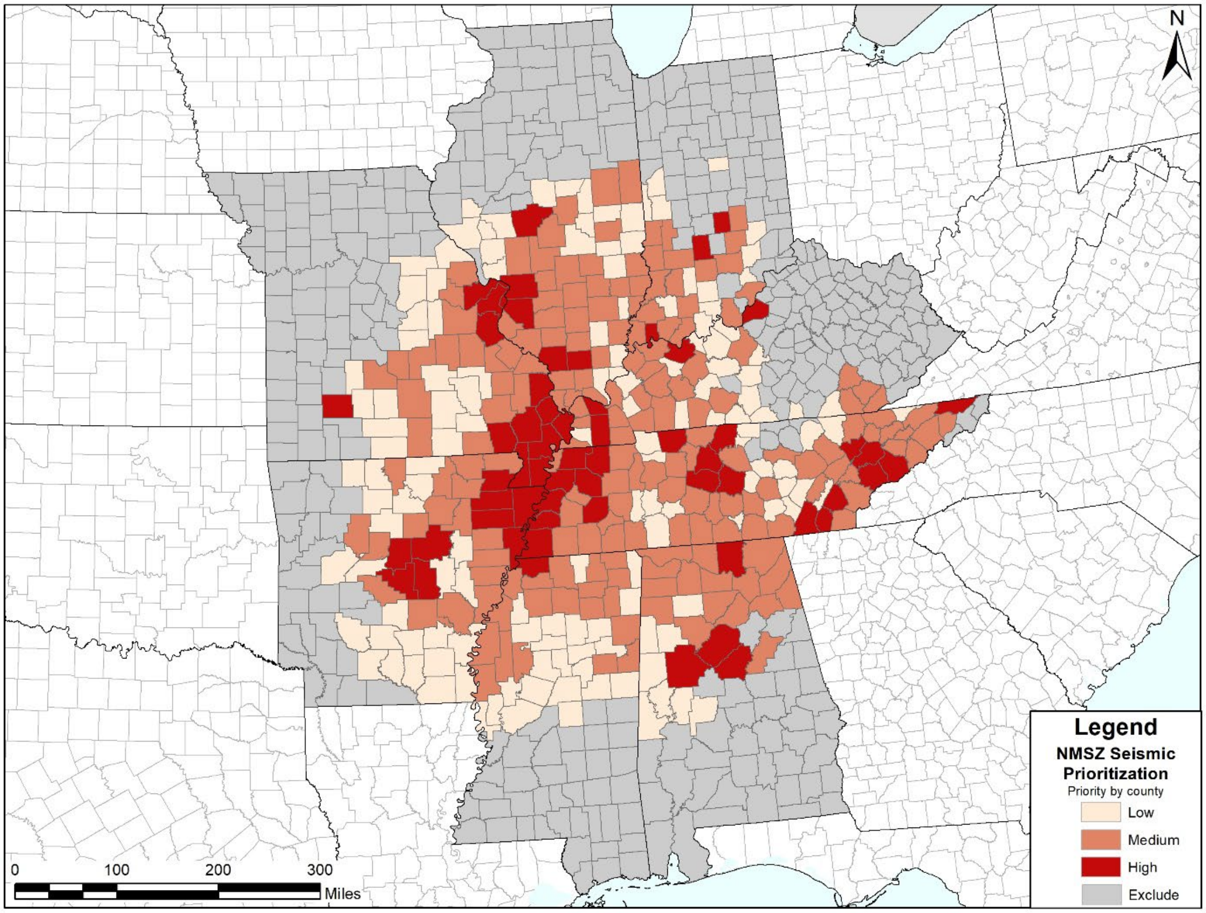


Figure F-15: Seismic Analysis Prioritization by county for the eight new Madrid Seismic Zone states

F.5.2 NMSZ States – NEHRP Soil

Census tract data for NEHRP soil type have been developed for the eight NMSZ states from USGS Vs30 data in a manner similar to that for the six western seismic states, as shown in Figure F-16.

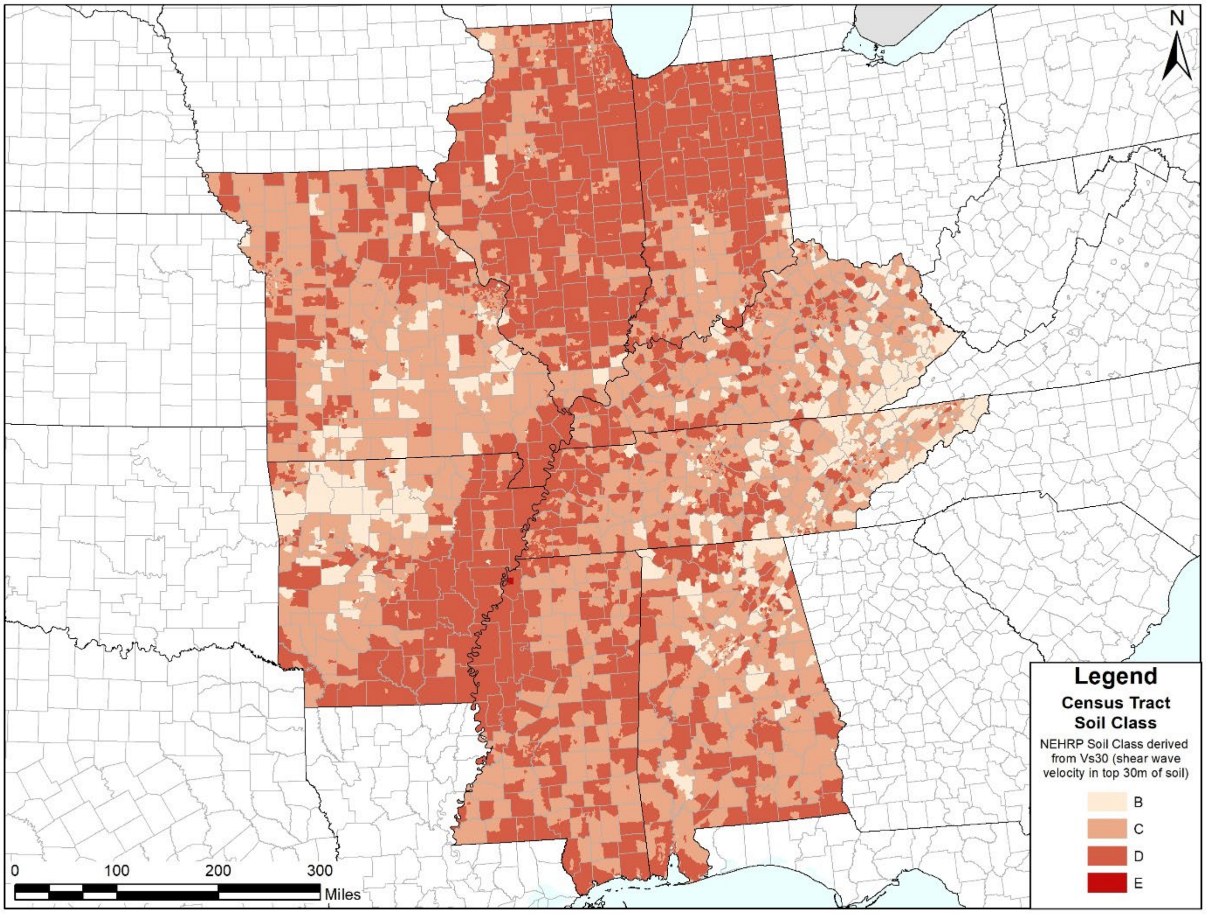


Figure F-16: NEHRP soil class by census tract for the eight New Madrid Seismic Zone states (derived from USGS Vs30 grid data)

F.5.3 NMSZ States – Code Adoption History

Since the year 2000, when the IBC first became available, few states in the NMSZ have enforced statewide building codes as minimum requirements. Rather, building codes are often adopted and enforced at the local level in jurisdictions smaller than individual counties. Over this time, several states in the NMSZ have begun to adopt statewide building codes as minimum requirements; however, (1) there are several examples of states providing a path for local jurisdictions to opt-out of or “weaken” statewide requirements via local amendments; and (2) the overall code adoption history and enforcement since the year 2000 in this region remains largely based on the adoption history of the local jurisdictions. An overview of the code adoption history by state is provided below.

- Alabama does not have a statewide building code. However, more recently, many local jurisdictions have adopted the building codes specified by the Division of Construction Management in the Alabama Department of Finance.
- Arkansas currently has a statewide Fire Prevention Code that incorporates the International Building Code and International Residential Code, and requires local jurisdictions to comply with these or more stringent requirements.
- Illinois does not have a statewide building code.
- Indiana currently enforces a statewide building code, and requires local jurisdictions to comply with these or more stringent requirements.
- Kentucky enforces a statewide building code, but has a history of weakening the model building code by downgrading the designated seismic design categories to lower levels.
- Mississippi does not mandate that local jurisdictions adopt buildings codes. If the local jurisdictions choose to adopt, the codes must be the codes approved by the State Building Code Council.
- Missouri does not have a statewide building code.
- Tennessee currently enforces a statewide building code.

Of the 60 counties identified as high-priority counties, eight example counties—the one with the highest hazard (peak ground acceleration [PGA] x Population) in each state in the NMSZ—were identified to evaluate the level of effort involved in determining building code adoption history when driven by local jurisdictions and varying levels of statewide building code adoption. For each of the eight identified counties, the following procedure was used to identify and research the code adoption history for significant local jurisdictions within the county:

- Determine county population based on 2010 United States Census results.
- Sort BCEGS data to get a list of all jurisdictions in the county.
- Identify potentially larger jurisdictions based on a map of the county.
- Determine populations of identified jurisdictions based on 2010 United States Census results to ensure that a significant percentage of the county population is covered by these jurisdictions.
- Review state, county, and local jurisdiction websites for current (2019) building code adoption information.
- Review BCEGS data for comparison with information found from jurisdiction websites.

A summary of the results of this example counties study is as follows:

- Jefferson County, Alabama (Birmingham Metro Area) – Currently shows relatively uniform adoption of the 2015 International Building Codes.
- Pulaski County, Arkansas (Little Rock Metro Area) – Currently shows relatively uniform adoption of the 2012 Arkansas Fire Prevention Code.
- St. Clair County, Illinois (St. Louis Metro Area) – Currently shows variability between jurisdictions in adoption of model building codes.
- Vanderburgh County, Indiana (Evansville Metro Area) – Jurisdictions currently reference statewide building codes in Indiana.
- Jefferson County, Kentucky (Louisville Metro Area) – Jurisdictions currently reference statewide building codes in Kentucky.
- De Soto County, Mississippi (Memphis Metro Area) - Currently shows relatively uniform adoption of the 2012 International Building Codes.
- St. Louis County, Missouri (St. Louis Metro Area) – Currently shows relatively uniform adoption of the 2018 International Building Codes.
- Shelby County, Tennessee (Memphis Metro Area) – Currently shows relatively uniform adoption of the 2015 International Building Codes.

Although current code provisions for local jurisdictions are generally available on jurisdiction websites and are easy to find, code adoption history is generally much less readily available online. It is also anticipated that even current code provisions will be less readily available in less densely populated jurisdictions throughout the NMSZ. Code adoption history for each jurisdiction would need to be gathered on an ad hoc basis for all jurisdictions in the 265 medium- and high-priority counties, based on published materials, information available online, or by querying local officials. Therefore, the BCEGS data are likely the best source of readily available code adoption history. For use in a NMSZ Loss Avoidance Study, the BCEGS database information would need to be output to a spreadsheet with a one-to-one correspondence between local jurisdiction and building code adoption history by year. In other words, there would be a column for every jurisdiction, and then a column for each year from 2000 to present, with an entry for the building code under enforcement in that jurisdiction in that year. Code adoption history contained in the BCEGS data is limited by reporting years, so this methodology would have the risk of missing potential code adoption history between reporting years.

A further complication is that most states in the NMSZ allow adoption of the IBCs that have somehow been “weakened.” This could be accomplished by locally changing the hazard mapping or by relaxing code limitations on structural systems or seismic detailing. Such changes could change the appropriate Hazus Design Level to be assigned. Weakening revisions to local seismic codes are noted in the FEMA Building Science Branch Code Monitoring Quarterly Reports, also made available for the current LAS project, and appear to be fairly common. These cases must be investigated individually, and appropriate methods to revise the Hazus Design Levels will also need to be determined when the LAS is fully implemented.

Before the required code adoption history is developed, a clarification of the intent of a NMSZ LAS is needed.

1. **With Weakening**: Would an eventual NMSZ LAS study be wholly consistent with the current LAS study? That is, are we trying to estimate actual losses avoided through code adoption by comparing the performance of buildings as-built to any I-Code edition, including weakened I-Codes in many NMSZ communities, to performance of the same building designed to the code in use before initial adoption of the I-Codes? In this case, use of each weakened code must be identified and investigated, significantly increasing the scope of the eventual LAS compared to the study in the west.
2. **Without Weakening:** Should we be demonstrating the hypothetical losses that would have been avoided by adoption of the full/unweakened I-Codes? That is, comparing performance of buildings had they been built to the full, unweakened code edition adopted in the year built, to performance of the same building designed to the code in use before initial adoption of the I-Codes.

These two approaches require substantially different code adoption history development efforts, as well as different design-level development efforts in future phases.

F.5.4 Extrapolation of the Current BCS Study Results for the Western States to the NMSZ States

In an effort to develop a ball-park estimate of the potential loss avoided through I-Code adoption for the eight states in the NMSZ—Alabama, Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee—an extrapolation exercise has been conducted using:

- Building Codes Save (BCS) results from the detailed assessments in the six western seismic states
- CoreLogic-derived exposure data for post-2000 construction in the eight NMSZ states
- Results from FEMA’s most recent Hazus national earthquake AAL study (FEMA, 2017)

The primary results from the 2017 national Hazus earthquake AAL study are AELs (annual earthquake losses, in \$) and AELRs (annual earthquake loss ratios, \$/\$M exposed) for the full Hazus default inventory.[6] These losses reflect the full range of Hazus direct economic losses, including building and contents damage, commercial inventory loss, and building-damage-related business interruption losses, including lost rent, relocation costs, and lost wages and income.

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[6] Estimated using Hazus 3.0, in 2014$

The current BCS Study has produced earthquake AALs (and normalized AALs, AAL/Building Exposure, equivalent to AELRs) for post-2000 exposures, modeled for pre-I-Code and I-Code exposures, reflecting building and contents damage only.[7] While inventory and business interruption losses may be estimated using the Hazus Earthquake AEBM methods, similar computations are not possible in the flood or hurricane wind methods applied in this project. Accordingly, for consistency across the various hazards, inventory and income loss results are not included in the results provided in the main BCS Study report but are provided for California only (see Section F.4.3). The magnitude of these unmodeled losses is not large; estimated commercial inventory losses for California totaled just 1% of those for building damage, and business interruption losses were 12 to 13% of building damage.

F.5.4.1 BCS Results Used in the NMSZ Extrapolation

The current BCS Study results for the six western seismic states have been used to develop two ratios for each state: the ratio of pre-I-Code normalized AAL (pre-I-Code AAL/building exposure for post-2000 construction) to Hazus full AELR, and the ratio of I-Code normalized AAL (I-Code AAL/building exposure for post-2000 exposure) to Hazus full AELR, given in Table F-32. The difference between the two ratios reflects the magnitude of the expected loss avoided; Alaska, which has the smallest loss avoided (see Section 6.3.1), shows a 1% difference between the pre-I-Code and the I-Code ratio; while Hawaii, which has the largest loss avoided on a percentage basis, shows a 17% difference.

These ratios, selected a) individually, and b) averaged, have been used to extrapolate results to the non-modeled NMSZ states by multiplying the pre-I-Code and I-Code ratio by the selected state’s estimated post-2000 exposure value from the processed CoreLogic data. This yields very approximate AALs (see Section F.5.3 for a full discussion of the limitations of this approach) with and without I-Codes, as well as losses avoided, that are consistent with the 2017 FEMA study.

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[7] Estimated using Hazus 4.2 SP03, in 2018$. A custom Hazus module to estimate AAL for building-specific data using the Hazus Advanced Engineering Building Module (AEBM) was developed for this project.

Table F-32: Summary of Pre-I-Code and I-Code Normalized AALs and Ratios Relative to full Hazus AELRs for the Six Western Seismic States

State	Normalized Pre-I-Code AAL: Pre-I-Code AAL/Building Exposure ($/$M)	Normalized I-Code AAL: I-Code AAL/Building Exposure ($/$M)	FEMA P-366 (FEMA, 2017a) AELR ($/$M)	Normalized Pre-I-Code AAL / Hazus full AELR	Normalized I-Code AAL / Hazus full AELR	Loss Avoided as a Percent of Pre-I-Code AAL
AK	812	802	1,058	0.77	0.76	1%
CA	588	543	971	0.61	0.56	8%
HI	862	717	708	1.22	1.01	17%
OR	228	214	662	0.34	0.32	6%
UT	267	234	499	0.54	0.47	12%
WA	420	378	592	0.71	0.64	10%
Total	**517**	**474**	**870**	**0.59**	**0.55**	**8%**

F.5.4.2 CoreLogic Data for the NMSZ States

The fully processed post-2000 CoreLogic building data for the eight NMSZ states is summarized in Table F-33. As shown, the eight NMSZ states have about the same number of buildings as the six western seismic states (see Table 6-6), but with less total building square footage (6.5 million square feet in the NMSZ versus 7.9 million square feet in the six western seismic states), contributing to lower net replacement values.

Table F-33: Summary of Post-2000 Building Data for the NMSZ States

State	Building Count	Building Area (1,000 SF)	BRV ($M)	CRV ($M)
AL	351,452	891,888	$116,656	$74,259
AR	199,877	381,612	$43,381	$21,908
IL	260,969	824,765	$175,573	$102,395
IN	402,869	1,226,363	$191,888	$124,593
KY	185,879	434,268	$57,540	$37,513
MS	218,613	510,249	$60,745	$39,165
MO	310,277	769,501	$125,312	$76,402
TN	545,532	1,449,772	$184,840	$117,279
Total	**2,475,468**	**6,488,417**	**$955,934**	**$593,514**

F.5.4.3 Limitations of the Current Extrapolation Approach

To use the western states BCS Study results to estimate approximate NMSZ AALs and Average Annual Losses Avoided (AALA), a significant number of assumptions have been made. These assumptions are summarized in Table F-34, and described in detail below. These limitations should be borne in mind when reviewing the results of the extrapolation.

Table F-34: Assumptions Required to Implement the NMSZ Extrapolation

More Reasonable Assumptions	Less Reasonable Assumptions
✓ Similar development patterns	✗ Similar code adoption histories
✓ Hazard level differences are captured by the FEMA (2017a) AELR results	✗ Similar construction practices

✓Similar development patterns – this extrapolation approach assumes the NMSZ states have a development history similar to that of the western states. Based on a review of total construction counts over time (Figure F-17 and Figure F-18), the West and the NMSZ demonstrate similar construction patterns, including a post-2007 construction rate reduction, so this appears to be a reasonable assumption.

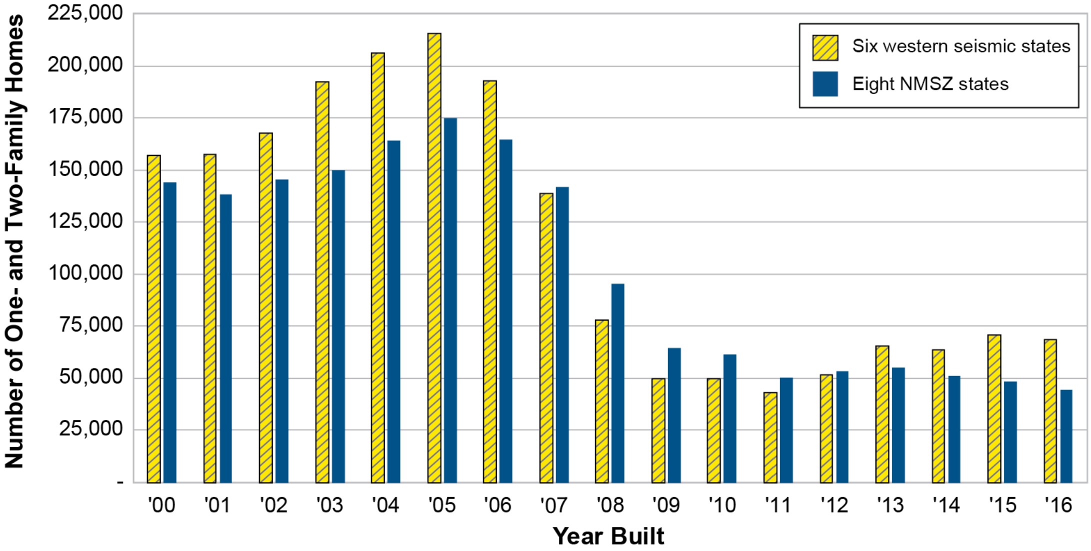

Figure F-17: Residential building counts for the six western seismic states and the eight NMSZ states

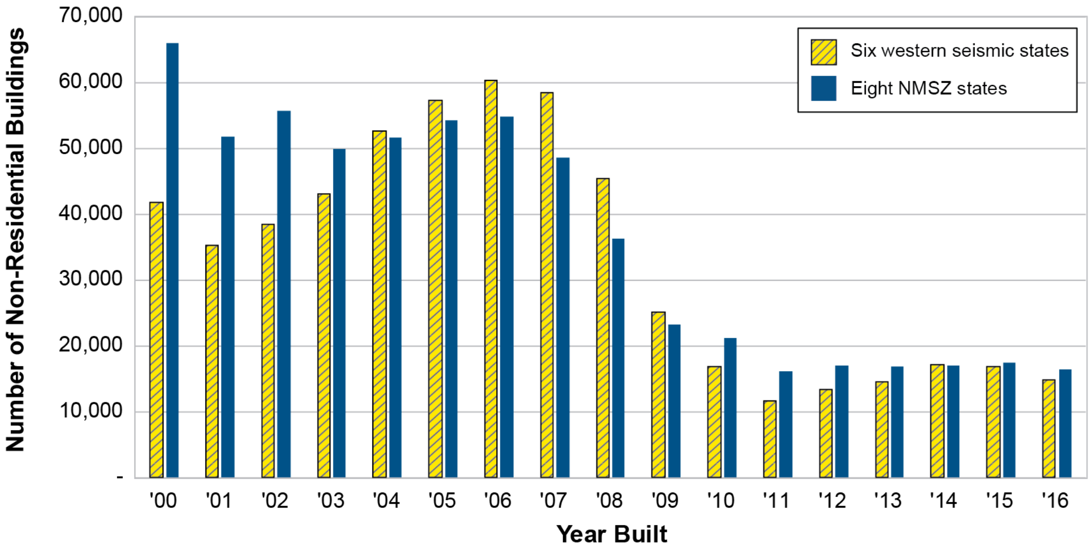

Figure F-18: Non-residential building counts for the six western seismic states and the eight NMSZ states

✓ Differences in hazard levels – the inherent differences in hazard levels between the west and the NMSZ are implicitly captured through the use of the results from FEMA's Hazus national earthquake AAL study as the basis for the extrapolation.

✗ Similar code adoption history – by extrapolating from the current BCS Study results for the western seismic states, this approach assumes that the NMSZ states have similar code adoption histories to the western states. While this a necessary assumption given available data, it may underestimate losses avoided for several reasons, as described below:

- The western states generally have statewide building codes. Based on preliminary review of code adoption in the NMSZ (see Section F.5.3 for additional details), five of the eight NMSZ states currently have a statewide building code (Arkansas, Indiana, Kentucky, Mississippi and Tennessee) and three do not (Alabama, Illinois and Missouri).
- The Western states have a long history of adopting seismic codes; except for residential construction in some unincorporated areas of Alaska, the western states had all adopted building codes prior to 2000. Per the available BCEGS data (see Section 3.1.2), multiple jurisdictions in the NMSZ states had no commercial or residential building code adopted prior to 2000 and beyond. **If a NMSZ jurisdiction adopted a building code for the first time during the time period under study (i.e., went from "no code" to "I-Code"), the losses avoided could be significantly larger than are being estimated.**
- The western states were mostly using UBC prior to 2000; adopted codes used in the NMSZ states include SBC (in Alabama, Arkansas, and Tennessee), BOCA (in Illinois and Kentucky), as well as UBC (in Indiana). Design levels for various hazard levels under the

codes used in the mid-west may not be similar to the Design Levels determined for the UBC in the West.

✗ Similar construction practices – this extrapolation approach assumes that the distribution of building types and sizes, and the associated MBTs used in the NMSZ would be similar to those in the West. This assumption is less than ideal; a quick review of available MBT information indicates that for similar construction profiles, the NMSZ states in many cases may use different MBTs than the western states.

F.5.4.4 Results of the Extrapolation

While Table F-32 provides ratios for each western seismic state, and for the group of states as a whole, the extrapolation has been conducted using two sets of ratios to provide a range of results. Utah has been selected as the analog state (the state with the most similarities to the NMSZ states), and the six western seismic state average has also been applied. Results of the extrapolation are provided in Table F-35. As shown in the table, the estimated AALs are largest in Tennessee and smallest in Alabama. Using the Utah-based extrapolation, the NMSZ states contribute 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 above in the limitations section (Section F.5.4.3), with detailed modeling of the NMSZ code history and construction practices, the net losses avoided could be significantly larger.

Table F-35: Extrapolated AAL and AALA for the NMSZ States

	Extrapolation Based on Utah's BCS Study Results			Extrapolation Based on Six Western Seismic States Average BCS Study Results		
State	**Estimated Pre-I-Code AAL ($1,000)**	**Estimated I-Code AAL ($1,000)**	**Estimated AALA ($1,000)**	**Estimated Pre-I-Code AAL ($1,000)**	**Estimated I-Code AAL ($1,000)**	**Estimated AALA ($1,000)**
AL	$2,479	$2,173	$306	$2,753	$2,526	$227
AR	$4,075	$3,571	$503	$4,526	$4,152	$374
IL	$4,247	$3,723	$525	$4,717	$4,328	$389
IN	$4,704	$4,123	$581	$5,224	$4,793	$431
KY	$2,895	$2,537	$358	$3,215	$2,950	$265
MS	$2,702	$2,368	$334	$3,001	$2,753	$248
MO	$7,914	$6,937	$978	$8,790	$8,064	$726
TN	$20,528	$17,992	$2,536	$22,799	$20,917	$1,882
Total	**$49,543**	**$43,424**	**$6,120**	**$55,024**	**$50,482**	**$4,542**