6. VULNERABILITY TO FLASH FLOODING CAUSED BY EXTREME PRECIPITATION

Methods

Flash flood events represent an area of overlap between meteorology, geology, topography, and hydrology that is not well understood. The one necessary and underlying component of flash flooding is precipitation; without rain, the probability of flash flooding is zero. Beyond that, the characteristics of an area that cause flash flooding are variable across the landscape. In some places like Big Thompson Canyon in Colorado, a deadly flood in 1976 was as much a function of slope and impermeable surfaces as it was the rainfall preceding the event. Florida, however, presents a distinctly different landscape where slopes are generally not very large, yet the possibility of flash flooding and ponding is still an ever-present threat. Climate science points to a future where the overall rainfall is about the same as today, meaning that Florida should expect to see the same annual average volume of water to fall in one year. However, these same predictions also indicate that rainfall events will be less frequent and more severe. The location of severe rainfall events cannot currently be modeled with certainty. In lieu of identified geographic areas where more rainfall will be found in Florida, a modeled surface of flash flood potential index is used to identify areas of interest for planning and adaptation.

The Flash Flood Potential Index (FFPI)

The goal of the FFPI is to empirically define a place's risk of flash flooding based on its pre-event characteristics: slope, land cover, soil drainability, and land use. The FFPI is an index allowing users to see which places are more pre-disposed to flash flooding than others are. The FFPI has been applied to numerous areas across the United States using different weighting combinations depending on the focus area.

First, Smith (2003) developed the FFPI for the Colorado River basin as a supplement to the Flash Flood Monitoring and Prediction System. The FFPI was originally created by Smith because limitations in conventional flash flood guidance lead to inaccurate flash flood forecasts. Limitations addressed by Smith included base data scale, the coarse resolution of soil data, and the need to use a long time series of hydrological data to calibrate the model. The original FFPI developed GIS raster surfaces for each of the four inputs (slope, land use/land cover, soil type/texture, and vegetation cover or density). Each of these was scaled from 1 – 10, added in a weighted linear model where values for M are more than 1, and divided by 4 to derive a final FFPI between 1 – 10 (equation below).

$$FFPI = \frac{M + L + S + V}{N}$$

Where

M = Slope

L = Land Cover/Use

S= Soil Type/ Texture

V = Vegetation Cover/Forest Density

N = Number of input variables. (L, S, and V are given weights of 1. Max N is greater than 4 since M was given a weight slightly higher than 1 because of the significant influence slope has in flash flood development [Smith, 2003]).

In 2009, Brewster modified the original Smith version of the FFPI for implementation in Binghamton, NY. This version of the model gave greater weight to the slope and vegetation cover than the land use and soil type, effectively prescribing great flash flood potential to areas with greater slope (equation below).

$$FFPI = \frac{1.5(M) + L + S + 0.5(V)}{4}$$

Kruzdlo (2010) implemented the FFPI for State College, Pennsylvania where the FFPI equation diverges from the original Smith FFPI by utilizing an equal weighting scheme originated by Smith (2003). Ceru (2012) modified the initial State College equation to give higher weighting to slope and land use/land cover based on “precedence from previous runs of FFPI at other offices, and consulting hydrologists at the Mid Atlantic River Forecast Center” (Ceru, 2012, slide 21) (equation below).

$$FFPI = \frac{M + L + S + V}{4}$$

Where

N = Number of input variables. (L, S, and V are given weights of 1. Max N is greater than 4 since slope and land use/cover were given a weight slightly higher than 1[Smith, 2003]).

Most recently, Zogg and Deitsch (2013) implemented each of the proposed equations for FFPI for Des Moines, Iowa. The authors took care to provide many details about the sources and preparation of the data for use in the FFPI. For each input, they describe source data, manipulation of data to standardize and normalize, and the process used to combine the data.

This report utilized findings from Zogg and Deitsch (2013) to create an ArcGIS model to define FFPI for Florida. The average value for each tract was chosen to represent flash flood risk in lieu of maximum value because nearly every tract has a maximum flash flood potential near 100%. However, while the maximum for each tract is very high, the number of grid cells (land area) characterized by this value is generally low in each tract. Using average FFPI value highlights areas where higher values dominate across the area. The average FFPI value for each census tract represents cumulative exposure. Each tract was then categorized into one of four classes based on the level of flash flood potential using the following equal interval classification scheme so that future changes in risk at the tract-level can be easily seen in comparison to the current risk level:

- Low = Less than 2.5 FFPI
- Medium = Between 2.5 – 5 FFPI
- High = Between 5 – 7.5 FFPI
- Extreme = Greater than 7.5 FFPI

A straight additive model was implemented for Florida because of a lack of *a priori* understanding of input variable importance. The FFPI for Florida (Figure 28) fits well with known geographic variations across the state related to slope and land cover.

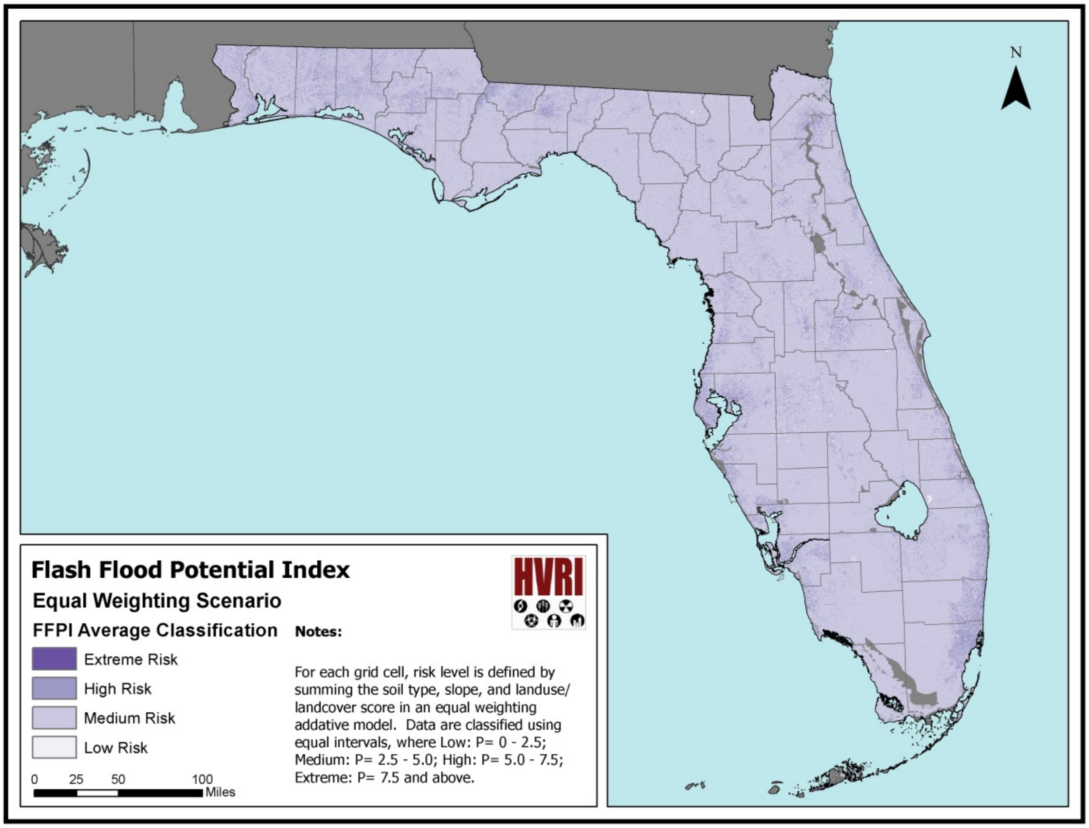

Figure 28: Flash flood potential index surface for Florida.

State Summary

The pattern of average FFPI for each county in Florida displays a pattern of high flash flood risk in urban areas surrounding Cape Coral, Jacksonville, Miami, Tampa, and Tallahassee (Figure 29). Very few places in and around Orlando have high flash flood potential, indicating that the model does not merely mimic urban areas. However, the Clermont area in central Florida has a high flash flood probability stemming from the many lakes and drastic (albeit small) slope changes in the area (Figure 30). Nine counties, including Broward, Collier, Duval, Hillsborough, Lee, Leon, Miami-Dade, Palm Beach, and Pinellas, each have more than 50,000 people living in areas with high average FFPI census tracts including nearly 80% of tracts and nearly 2,000,000 people in Miami-Dade County alone (Table 41 and Table 42). Nearly 50% of Monroe County tracts and 30% of Broward County tracts add 500,000 more people to the list of those at high risk from flash flooding should extreme precipitation occur.

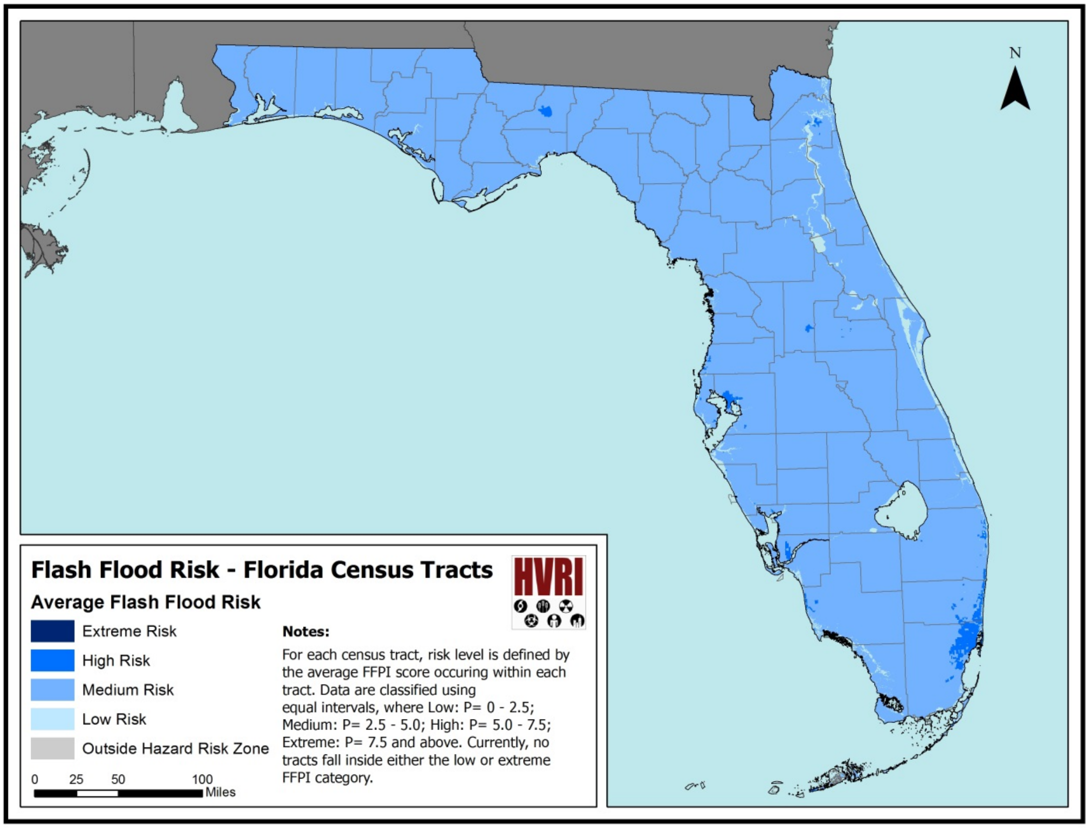

Figure 29: Average flash flood risk for Florida census tracts.

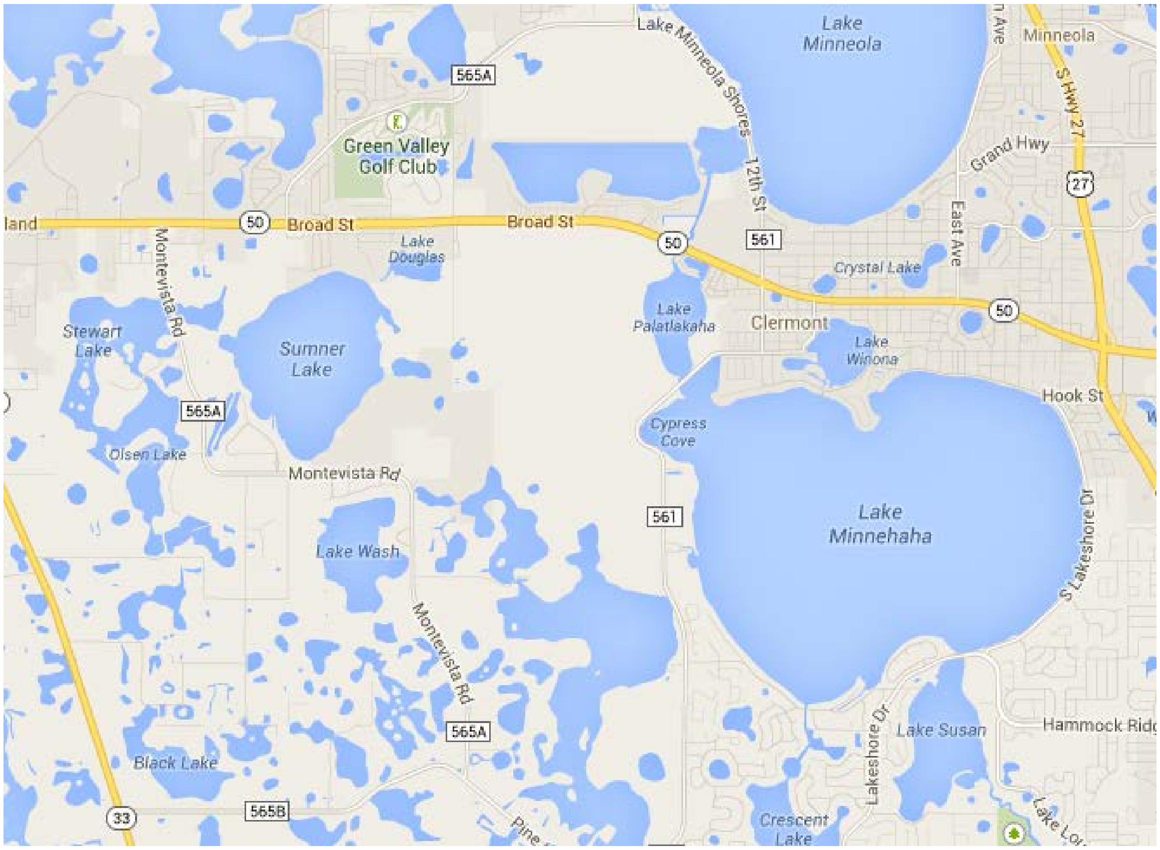

Figure 30: Clermont area surface hydrology.

Table 41: Census tract summary for flash flood hazard risk.

County Name	Flash Flood Hazard Risk					County Name	Flash Flood Hazard Risk				
	Extreme (> 7.5)	High (5 - 7.5)	Medium (2.5-5)	Low (<2.5)	Out		Extreme (> 7.5)	High (5 - 7.5)	Medium (2.5-5)	Low (<2.5)	Out
Alachua	-	-	100.00%	-	-	Lee	-	10.18%	89.82%	-	-
Baker	-	-	100.00%	-	-	Leon	-	44.12%	55.88%	-	-
Bay	-	6.82%	93.18%	-	-	Levy	-	-	100.00%	-	-
Bradford	-	-	100.00%	-	-	Liberty	-	-	100.00%	-	-
Brevard	-	4.42%	95.58%	-	-	Madison	-	-	100.00%	-	-
Broward	-	29.64%	70.36%	-	-	Manatee	-	1.28%	98.72%	-	-
Calhoun	-	-	100.00%	-	-	Marion	-	-	100.00%	-	-
Charlotte	-	12.82%	87.18%	-	-	Martin	-	2.94%	97.06%	-	-
Citrus	-	-	100.00%	-	-	Miami-Dade	-	79.58%	20.42%	-	-
Clay	-	-	100.00%	-	-	Monroe	-	45.16%	54.84%	-	-
Collier	-	29.73%	70.27%	-	-	Nassau	-	-	100.00%	-	-
Columbia	-	-	100.00%	-	-	Okaloosa	-	7.32%	92.68%	-	-
DeSoto	-	-	100.00%	-	-	Okeechobee	-	-	100.00%	-	-
Dixie	-	-	100.00%	-	-	Orange	-	2.42%	97.58%	-	-
Duval	-	9.25%	90.75%	-	-	Osceola	-	-	100.00%	-	-
Escambia	-	7.04%	92.96%	-	-	Palm Beach	-	13.39%	86.61%	-	-
Flagler	-	-	100.00%	-	-	Pasco	-	8.96%	91.04%	-	-
Franklin	-	-	100.00%	-	-	Pinellas	-	8.98%	91.02%	-	-
Gadsden	-	-	100.00%	-	-	Polk	-	-	100.00%	-	-
Gilchrist	-	-	100.00%	-	-	Putnam	-	-	100.00%	-	-
Glades	-	-	100.00%	-	-	Santa Rosa	-	-	100.00%	-	-
Gulf	-	-	100.00%	-	-	Sarasota	-	4.26%	95.74%	-	-
Hamilton	-	-	100.00%	-	-	Seminole	-	-	100.00%	-	-
Hardee	-	-	100.00%	-	-	St. Johns	-	2.56%	97.44%	-	-
Hendry	-	-	100.00%	-	-	St. Lucie	-	2.27%	97.73%	-	-
Hernando	-	-	100.00%	-	-	Sumter	-	-	100.00%	-	-
Highlands	-	-	100.00%	-	-	Suwannee	-	-	100.00%	-	-
Hillsborough	-	17.13%	82.87%	-	-	Taylor	-	-	100.00%	-	-
Holmes	-	-	100.00%	-	-	Union	-	-	100.00%	-	-
Indian River	-	-	100.00%	-	-	Volusia	-	5.26%	94.74%	-	-
Jackson	-	-	100.00%	-	-	Wakulla	-	-	100.00%	-	-
Jefferson	-	-	100.00%	-	-	Walton	-	-	100.00%	-	-
Lafayette	-	-	100.00%	-	-	Washington	-	-	100.00%	-	-
Lake	-	1.79%	98.21%	-	-	**State Total**	-	18.84%	81.16%	-	-

Table 42: Census tract population summary for flash flood hazard risk.

County Name	Flash Flood Hazard Risk: Extreme (> 7.5)	High (5 - 7.5)	Medium (2.5-5)	Low (<2.5)	Out	County Name	Flash Flood Hazard Risk: Extreme (> 7.5)	High (5 - 7.5)	Medium (2.5-5)	Low (<2.5)	Out
Alachua	-	-	247,336	-	-	Lee	-	69,383	549,371	-	-
Baker	-	-	27,115	-	-	Leon	-	115,286	160,201	-	-
Bay	-	3,947	164,905	-	-	Levy	-	-	40,801	-	-
Bradford	-	-	28,520	-	-	Liberty	-	-	8,365	-	-
Brevard	-	12,807	530,562	-	-	Madison	-	-	19,224	-	-
Broward	-	456,143	1,291,923	-	-	Manatee	-	1,682	321,151	-	-
Calhoun	-	-	14,625	-	-	Marion	-	-	331,298	-	-
Charlotte	-	12,207	147,771	-	-	Martin	-	1,998	144,320	-	-
Citrus	-	-	141,236	-	-	Miami-Dade	-	1,959,826	533,301	-	-
Clay	-	-	190,865	-	-	Monroe	-	41,783	31,307	-	-
Collier	-	66,314	255,206	-	-	Nassau	-	-	73,314	-	-
Columbia	-	-	67,531	-	-	Okaloosa	-	4,618	176,204	-	-
DeSoto	-	-	34,862	-	-	Okeechobee	-	-	39,996	-	-
Dixie	-	-	16,422	-	-	Orange	-	15,778	1,130,178	-	-
Duval	-	64,687	799,576	-	-	Osceola	-	-	268,685	-	-
Escambia	-	11,830	285,789	-	-	Palm Beach	-	143,821	1,175,641	-	-
Flagler	-	-	95,696	-	-	Pasco	-	39,180	425,517	-	-
Franklin	-	-	11,549	-	-	Pinellas	-	56,668	859,874	-	-
Gadsden	-	-	46,389	-	-	Polk	-	-	602,095	-	-
Gilchrist	-	-	16,939	-	-	Putnam	-	-	74,364	-	-
Glades	-	-	12,884	-	-	Santa Rosa	-	-	151,372	-	-
Gulf	-	-	15,863	-	-	Sarasota	-	10,438	369,010	-	-
Hamilton	-	-	14,799	-	-	Seminole	-	-	422,718	-	-
Hardee	-	-	27,731	-	-	St. Johns	-	1,931	188,108	-	-
Hendry	-	-	39,140	-	-	St. Lucie	-	925	276,864	-	-
Hernando	-	-	172,778	-	-	Sumter	-	-	87,023	-	-
Highlands	-	-	98,786	-	-	Suwannee	-	-	41,551	-	-
Hillsborough	-	182,965	1,046,261	-	-	Taylor	-	-	22,570	-	-
Holmes	-	-	19,927	-	-	Union	-	-	15,535	-	-
Indian River	-	-	138,028	-	-	Volusia	-	16,480	478,113	-	-
Jackson	-	-	49,746	-	-	Wakulla	-	-	30,776	-	-
Jefferson	-	-	14,761	-	-	Walton	-	-	55,043	-	-
Lafayette	-	-	8,870	-	-	Washington	-	-	24,896	-	-
Lake	-	17,784	279,268	-	-	**State Total**	**-**	**3,308,481**	**15,482,445**	**-**	**-**

Analyzing Flash Flooding Hazard in Combination with SoVI and MedVI

About Bivariate Classifications

Here, we keep the exposure constant by using the same hazard threat surface but use different vulnerability perspectives (social and medical) in bivariate representations to create an easily understood depiction of not only increased threat but also a limited ability to adequately prepare for and respond to these threats. In doing so, we are able to quickly identify three specific geographic areas of interest:

1. Areas where the hazard itself should be the focus of planning and mitigation,
2. Areas where understanding the underlying socioeconomics and demographics would prove to be the most advantageous input point to create positive change, and
3. Areas where a combination of classic hazard mitigation techniques and social mitigation practices should be utilized in order to maximize optimal outcomes.

The following maps utilize a three by three bivariate representation in which one can easily identify areas of limited to elevated SoVI in relation to areas with low to extreme hazard classifications. Places identified in item number one in the preceding list are shaded in the blue colors and can be understood as locations where hazard susceptibility is higher than SoVI or MedVI. Areas identified in item number two above, indicating where socioeconomics and demographics play an important role, are shaded in the pink/red colors and can be conceived as locations where SoVI or MedVI are greater than physical hazard threats. Places identified in item number three above are shaded either in gray-tones or in a dark burgundy color and can be understood as areas that have equal vulnerability and hazard classification scores.

Integrating Flash Flood Hazard Risk with SoVI and MedVI

Areas where high flash flood risk and high SoVI coincide include the southeastern coast of Florida and the Tampa Bay area (Figure 31). In particular, large portions of Miami-Dade County where more than 1.5 million people reside in nearly 300 census tracts are included in this characterization (Table 43). Broward, Palm Beach, and Hillsborough Counties also have multiple tracts characterized by both high SoVI and high flash flood hazard risk. Here, 93,000, 54,000, and 46,000 residents, respectively, live in hazard-prone areas and may be less able to prepare for, respond to, and rebound from a disaster event. An additional 3.3 million people across 45 counties live in areas with a medium flash flood potential coupled with high SoVI (Table 43).

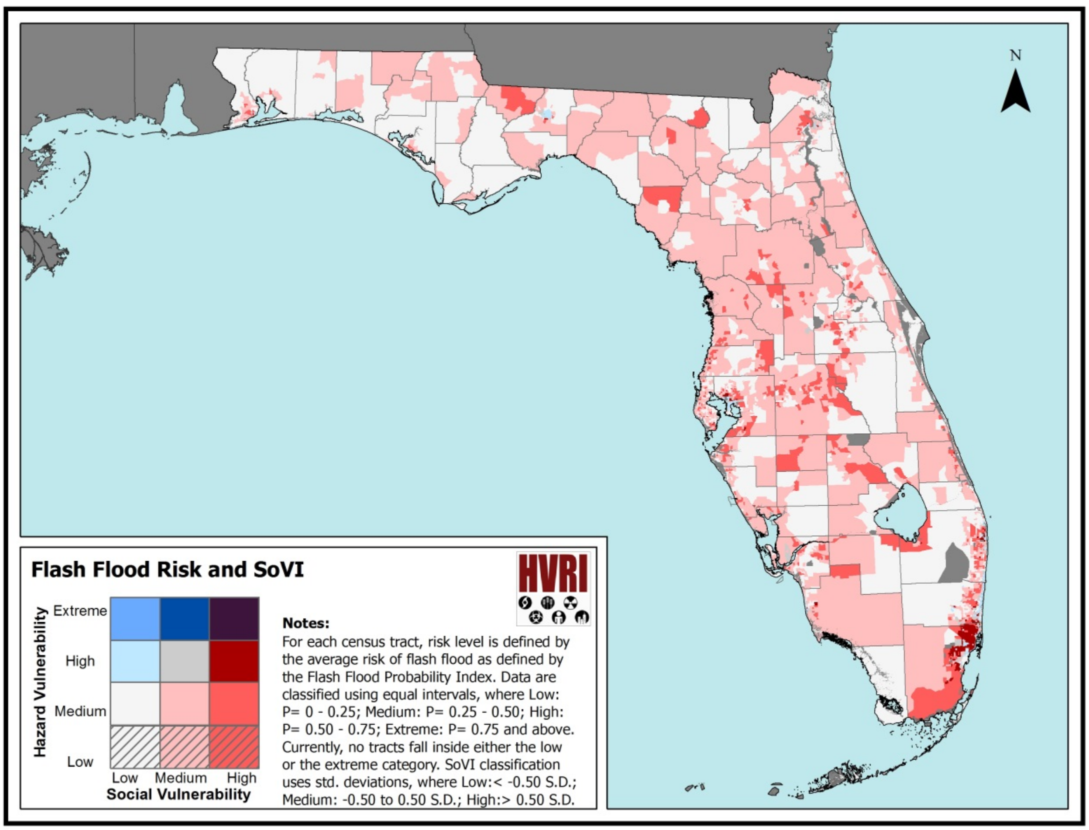

Figure 31: Bivariate representation of SoVI and flash flood hazard risk in Florida.

Table 43: Tract and population summary for counties with high SoVI and medium or greater flash flood hazard risk.

County Name	Number of Tracts	Total Population of Tracts		County Name	Number of Tracts	Total Population of Tracts		County Name	Number of Tracts	Total Population of Tracts
High Flash Flood Hazard Risk										
Broward	18	93,395		Collier	5	25,145		Duval	2	5,472
Escambia	1	1,864		Hillsborough	12	46,159		Leon	2	5,588
Miami-Dade	292	1,512,381		Orange	4	11,900		Palm Beach	18	54,556
Pasco	3	11,218		Pinellas	3	6,397		Sarasota	1	2,562
St. Lucie	1	925			-	-			-	-
State Total	**362**	**1,777,562**			-	-			-	-
Medium Flash Flood Hazard Risk										
Alachua	4	19,406		Bay	3	8,846		Brevard	6	20,847
Broward	93	456,153		Charlotte	5	17,905		Citrus	5	23,598
Clay	1	5,311		Collier	10	51,237		Columbia	1	2,872
DeSoto	3	13,900		Dixie	1	7,331		Duval	35	144,954
Escambia	11	38,059		Flagler	3	15,884		Gadsden	5	25,033
Hamilton	1	1,760		Hardee	2	10,630		Hendry	3	21,846
Hernando	15	62,301		Highlands	8	35,116		Hillsborough	61	233,626
Indian River	5	14,670		Lake	9	40,805		Lee	32	100,752
Leon	4	12,310		Manatee	19	84,453		Marion	15	102,216
Martin	2	4,091		Miami-Dade	67	388,240		Okeechobee	3	10,116
Orange	46	240,448		Osceola	14	103,651		Palm Beach	86	323,764
Pasco	25	76,024		Pinellas	34	126,265		Polk	52	219,460
Putnam	3	10,480		Santa Rosa	1	6,115		Sarasota	12	43,868
Seminole	7	25,901		St. Johns	1	4,155		St. Lucie	9	36,190
Sumter	6	52,106		Suwannee	1	7,016		Volusia	18	83,236
State Total	**747**	**3,332,947**			-	-			-	-

Coupling medical vulnerability with flash flood risk shows that a majority of the central peninsula and central panhandle have both high medical vulnerability and medium flash flood potential. Portions of Hillsborough and Lake Counties have high MedVI and high FFPI, while other places like Alachua, Orange, and Seminole Counties appear to be less vulnerable (Figure 32). Although these have the same hazard level as a majority of the state, their relatively low MedVI decreases overall risk to adverse outcomes. Table 44 indicates that the map does not tell the entire story. Here, we can see that there are eleven counties containing 65 tracts and more than 220,000 people characterized by high flash flood risk and high medical vulnerability. An additional 1,229 high MedVI tracts across 54 counties have 5.5 million residents located in medium flash flood potential areas.

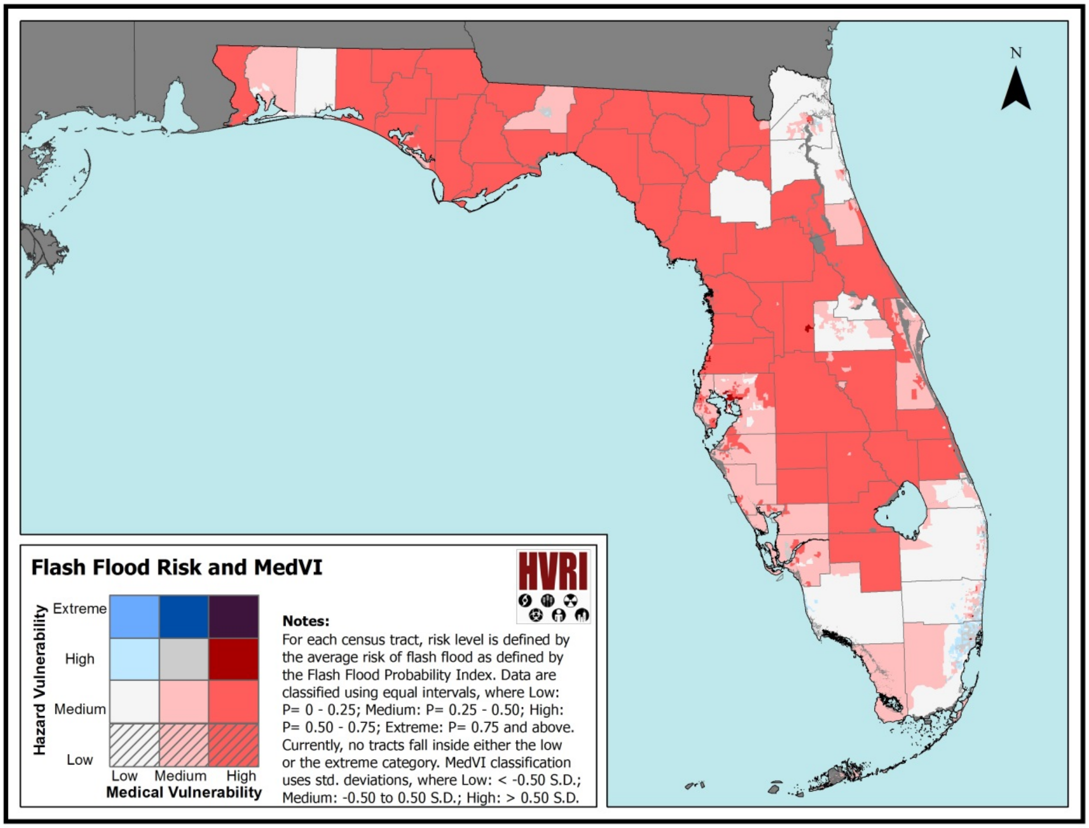

Figure 32: Bivariate representation of MedVI and flash flood hazard risk in Florida.

Table 44: Tract and population summary for counties with high MedVI and medium or greater flash flood hazard risk.

County Name	Number of Tracts	Total Population of Tracts	County Name	Number of Tracts	Total Population of Tracts	County Name	Number of Tracts	Total Population of Tracts
High Flash Flood Hazard Risk								
Bay	2	2,769	Broward	1	6,647	Duval	2	7,510
Escambia	5	11,830	Hillsborough	27	93,020	Lake	1	17,784
Miami-Dade	4	12,514	Pasco	12	39,180	Pinellas	4	15,947
St. Lucie	1	925	Volusia	6	16,480		-	-
State Total	**65**	**224,606**		-	-		-	-
Medium Flash Flood Hazard Risk								
Baker	3	20431	Bay	30	125027	Bradford	4	28520
Brevard	27	158,238	Broward	3	20,469	Calhoun	3	14,625
Charlotte	7	32,234	Citrus	27	141,236	Columbia	12	67,531
DeSoto	9	34,862	Dixie	3	16,422	Duval	8	27,311
Escambia	65	282,566	Flagler	6	24,521	Franklin	4	11,549
Gadsden	9	46,389	Gilchrist	5	16,939	Glades	3	12,884
Gulf	3	15,863	Hamilton	3	14,799	Hardee	6	27,731
Hendry	6	39,140	Hernando	44	172,778	Highlands	26	98,785
Hillsborough	58	214,906	Holmes	4	19,927	Indian River	29	138,028
Jackson	11	49,746	Jefferson	3	14,761	Lafayette	2	8,870
Lake	55	279,268	Lee	32	136,588	Levy	9	40,801
Liberty	2	8,365	Madison	5	19,224	Manatee	17	73,525
Marion	62	331,298	Okeechobee	11	39,996	Osceola	39	264,577
Pasco	119	419,530	Pinellas	64	257,045	Polk	153	602,092
Putnam	17	74,364	Sarasota	16	63,596	St. Johns	2	7,673
St. Lucie	42	276,864	Sumter	18	87,023	Suwannee	7	41,551
Taylor	4	22,570	Union	3	15,535	Volusia	107	478,113
Wakulla	4	30,776	Walton	11	55,043	Washington	7	24,896
State Total	**1,229**	**5,547,401**		-	-		-	-

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