Manufactured Housing Research Alliance

Review of HUD's Report of the Impact of Hurricane Charley on Manufactured Homes

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Review of HUD's Report on Hurricane Charley

A. Executive Summary

The Manufactured Housing Institute (MHI) requested that the Manufactured Housing Research Alliance (MHRA) conduct an independent assessment of the HUD report entitled, ***An Assessment of Damage to Manufactured Homes Caused by Hurricane Charley.*** The HUD report contained a survey of homes damaged by Hurricane Charley on August 13, 2004 and correlated damage to estimates of storm severity.

The MHRA review principally considers the merits of, and foundation for, the main conclusion reached by the HUD study authors: for homes located in Punta Gorda and Port Charles, Florida the storm was not a design event. It is MHRA's opinion that the HUD study conclusions, stated and implied, were far too broad given the tentative nature of the information collected and the small, non-representative sample of homes surveyed. Analyzing home performance in light of more contemporaneous storm data, MHRA found that for most of the homes surveyed the wind loads generated by Hurricane Charley exceeded design conditions.

Furthermore, homes built since 1994 (when the HUD standards were last revised with regard to wind load resistance) were virtually unscathed by the hurricane. Homes built since the 1999 Florida foundation requirements were implemented also survived the storm with little or no damage.

B. Introduction

On August 13, 2004 Hurricane Charley made landfall in the Southwestern Gulf Coast region of Florida (in the vicinity of Punta Gorda and Port Charles, FL). Following the Hurricane, the U.S. Department of Housing and Urban Development (HUD) dispatched a team that visited sites located in the immediate vicinity of the storm's path. The HUD team conducted a survey of 105 homes in 16 sites documenting the affect of the Hurricane. The results of the survey and conclusions were presented in a report entitled, ***An Assessment of Damage to Manufactured Homes Caused by Hurricane Charley*** [IBTS 2005].

Based on information collected by the team from the sites and from published weather data, the HUD report concluded that Hurricane Charley was not a *design* event. That is, for the homes and sites surveyed, the Hurricane produced wind loads below those stipulated in the HUD standards [HUD 1994] as minimum design conditions. On page 1, the HUD report states that, *"The wind pressures on the manufactured homes in the sample area were approximately 50 percent to 75 percent[1] of the design load for homes produced after July, 13, 1994 based on the updated HUD Code."*

While not explicitly stated in the HUD report, assessing the damage caused by Hurricane Charley while concluding that the homes did not experience design wind loads, is tantamount to testing the efficacy of the HUD standards and the quality of home construction. While noting that homes sustained damage under conditions less strenuous than required by the standards, the HUD report casts doubt as to the adequacy of the standards and/or industry's ability to build homes consistent with the design intent of the standards.

The Manufactured Housing Institute (MHI) requested that the Manufactured Housing Research Alliance (MHRA) conduct an independent assessment of the HUD study and the conclusions reached by its authors. In particular, MHRA was asked to review the data and analysis supporting HUD's conclusion that Hurricane Charley was not a design event for homes located in the Punta Gorda and Port Charles, FL areas.

The purpose of this review is to determine if HUD applied sufficient scientific rigor in reaching their conclusions and to consider the accuracy of the underlying data and analysis used to support their findings.

MHRA identified two main flaws in the HUD study methodology:

1. **The conclusions are too broad given the limits of HUD study**—The HUD study conclusions, stated and implied, were far too broad given the tentative nature of the information collected and the small, non-representative sample of homes surveyed. The report appropriately acknowledges that the storm metrics (particularly overland wind speeds) that are the basis for HUD's conclusions were preliminary and subject to change. Stating that the data supporting the engineering judgments are tentative is inconsistent with then drawing definitive conclusions based on those judgments. This is particularly the case when differences in judgment can fundamentally change the report conclusions.

   For example, despite the fact that the weather data cited in the study was preliminary and subject to change (a fact repeatedly acknowledged by the

[1] 50 percent of design load for main wind force resisting system and anchorage, and 75% for components and cladding.

authors) the principle conclusion of the report, that Hurricane Charley was *not* a design event, was put forward without reservation. This conclusion by the authors establishes a prism through which all the surveyed damage is then viewed, distorting other findings. That is, once it was concluded that the Hurricane was not a design event, any damage is viewed as a premature failure implying that HUD standards are not sufficiently stringent and/or the homes were not properly manufactured, designed or installed.

2. **The principle conclusion—Hurricane Charley was not a design event—is not supported by the data**. If the principle finding of the report, that Hurricane Charley was not a design event, overreaches given the limits of the data collection and analysis, it also rests on what appear to be shaky engineering assumptions. A detailed review of the data used in determining the wind loads suggests that most of the homes in the survey were, contrary to HUD's assertions, subjected to wind loads from Hurricane Charley that exceeded the threshold for a design event.

The discussions that follow provide the basis for these findings.

C. Analysis of the data underlying HUD's engineering judgments

The wind load provisions in the HUD standards are based on ***Minimum Design Loads for Buildings and Other Structures*** also referred to ASCE 7 [ASCE 1988]. ASCE 7 contains procedures for estimating the wind pressures experienced by a home. Pressure is a function of wind speed and wind speed depends primarily on the site's wind exposure class (an expression of degree to which the home is shielded from the wind by other structures and natural features of the terrain) and the maximum sustained wind speed (fastest mile) measured at a height of 33 feet above ground level.

The discussions below outline how values for these factors are derived, discuss their relative importance in predicting wind loads, describe the values derived by the authors of the HUD study and compare these with values developed by an independent engineer at the request of MHRA.

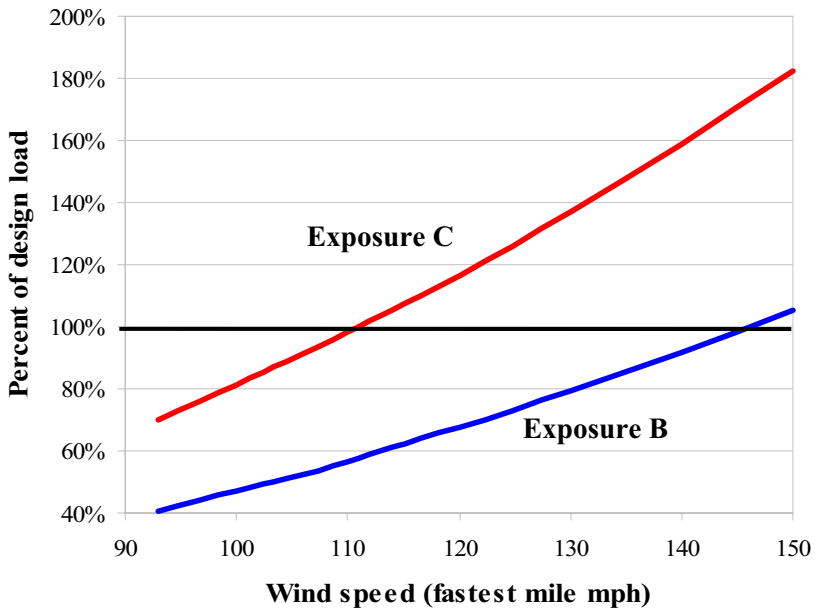
Site exposure classification

ASCE 7-88 defines four wind exposures ranging from exposure "A" (significant obstructions) to exposure "D" (no obstructions). The ASCE 7 exposure definitions are imprecise, leaving much up to interpretation, judgment and the experience of the engineer.

In applying the ASCE 7 calculation procedures, the magnitude of predicted wind loads is strongly linked with exposure class. As shown in Figure 1, changing the exposure class (from B to C in this example) while keeping the wind speed constant increases the load reached for a structure's main wind force resisting system by approximately 70%.[2]

[2] For example, at a wind speed of 130 mph, the percent of design load is 137% for exposure C compared with 79% if exposure B is assumed, an increase of 73% (137% - 79% = 58% / 79 = 73%).

Figure 1 Relationship of exposure and wind speeds to design pressure for the main wind force resisting system (MWFRS)



a. HUD analysis

The HUD team visited 16 sites near the Florida coastline and concluded that all fell within exposure class B as defined by ASCE 7.

As noted earlier, the selection of the exposure class depends to a large degree on engineering judgment. Exposure class is subjective and open to interpretation. There is clearly variation among the Florida sites and many are in open terrain and unshielded (as suggested by the aerial photos in Appendix A). The HUD report omits discussion of the potential significant variability in assigning exposure class despite the fact that changing this single assumption would alter the results and report conclusions.

b. Independent engineering assessment

At the request of MHRA, an independent engineer with manufactured housing expertise (John Doeden, P.E.) visited the sites and provided an assessment of the exposure class for each site based on detailed analysis of the windward exposures of each site [Doeden 2006]. Based on visual inspection of the sites and with the aide of pre-Charley aerial photographs and post-Charley field inspection reports, Mr. Doeden developed a site-specific assessment of the exposure classes. Results for the 16 sites are summarized on Table 1. Doeden assigned multiple exposure types to a few sites indicating that they were exposed to wind from more than one direction during the course of the storm. (Mr. Doeden's findings and related analysis are provided in Appendix A.)

Wind speed

The other factor that has a first order impact on ASCE 7-88-derived wind load estimates is the overall sustained (fastest mile) speed of the wind at 10 meters (33 feet) above ground level. It is often difficult to accurately gauge wind speeds at specific locations when, as was the case for the Florida sites, there are few reliable recording

stations. According to the National Hurricane Center, a division of NOAA, "*instrument failures remain a chronic problem in landfalling hurricanes*." [NHC 2004].

Table 1 Surveyed sites with exposure class

HUD site number	Site	Exposure class	
		HUD	Doeden
9	Burnt Store Colony	**B**	**C**
13	Buttonwood Village	**B**	**C**
14	By the Sea	**B**	**C**
8	Cherry Estates	**B**	**B**
17	Harbor View MHP	**B**	**C**
1	Lakewood Village	**B**	**C/B**
10	Park Hill	**B**	**C/B**
2	Pine Acres	**B**	**C/B**
7	Pine Island Cove	**B**	**B**
16	Port Charlotte Village	**B**	**B**
11	River Haven	**B**	**B**
4	River Oaks	**B**	**B**
14	S. Punta Gorda	**B**	**C**
5	September Estates	**B**	**B**
3	Ventura Lakes	**B**	**C/B**
12	Windmill MHP	**B**	**C**

a. HUD analysis

The HUD report claims that the homes in the sample area were subject to a maximum wind speed of 90 to 110 mph (1-minute sustained) at 33 feet from the ground. This estimate is based on a wind swath map (Figure 2) developed by NOAA using its experimental H*Wind computer model.

The HUD report acknowledges that the wind speed data supporting their analyses are, at best, preliminary estimates, including statements such as the following:

> "*. . . it will be some time before consensus is reached among experts to arrive at a consistent and scientifically agreed upon characterization of Hurricane Charley's wind field*." (Page 3)

> "*. . . any wind speeds reported herein should be considered as preliminary and subject to change as additional data and/or modeling results become available*." (Page 10)

H*Wind is an experimental computer model developed by scientists at NOAA that uses flight level data, surface observations, dropsonde data, remote sensing inputs, and knowledge of hurricane wind field characteristics to estimate a snapshot of the entire surface level wind field. The wind speed measurements used as inputs to the simulation are mostly sea-based measurements. According to NOAA, it is not unusual for land-based weather stations to lose power or become damaged in hurricanes, resulting in a dearth of reliable wind speed readings.[3]

In an attempt to compensate, researchers use the last known speeds at landfall in conjunction with the observed center position of the storm based on aircraft

[3] Conversation with NOAA scientist, Nov. 7, 2005 and NOAA Tropical Cyclone Report Hurricane Charley. NOAA admits that it has "not a lot of data over land" to generate the wind swath maps.

measurements and radar.[4] A decay model is then applied to this data to estimate the change in wind speeds as the storm moves ashore.

The HUD report and NOAA on its website both note that the H*Wind computer model is highly experimental. According to NOAA, the model should be updated as more accurate wind speed estimates become available. However, while they recognize the limits of the data, developing more precise wind speed estimates has not been a NOAA funding priority. Therefore, the NOAA wind swath map—the basis for the HUD analysis—is, at best a rough approximation of the wind speeds at the 16 sites.

Further, Hurricane Charley is characterized as a very tight storm[5] [NHC 2004(2)] (i.e. the eye was small and the storm had a very sharp wind speed gradient). Even a minor error of a couple of miles in the storm's center position as estimated by NOAA (which is very possible according to NOAA) would substantially redistribute and reposition the wind speed contours, resulting in considerably higher or lower estimated wind speeds at any given location.

In summary, the NOAA map is a blunt tool that should not be used for estimating with any precision the storm's wind speeds or for locating its path over land. Using this map to assign even approximate wind speeds to specific locations is of questionable value.

Compounding the flaws in HUD's wind speed analysis, the authors of the HUD report introduce several simplifying assumptions that impact the errors in projecting wind speeds. For example, HUD used 100 mph as the typical fastest-mile[6] wind speed for the purposes of calculating resulting wind pressures for all sites. However, their own estimates range from 93 to 114 mph (a midpoint of 103.5 mph). Such small differences in wind speed are important as, according to NOAA, ". . . *the amount of damage…does not increase linearly with the wind speed. Instead, the damage produced increases exponentially with the winds. The 148 mph hurricane (a category 4 on the Saffir-Simpson Scale) may produce, on average, up to 250 times the damage of a minimal category 1 hurricane!*"[7]

b. Independent engineers assessment

Doeden offers an alternative method for estimating wind speeds at the 16 sites based on Doppler radar images to determine the track of the hurricane (see Figure 3). This closely coincides with the HAZUS-MH wind methodology [FEMA 2005] determined to be the most accurate track, rather than the track modeled by NOAA.

As can be seen in Figure 3, the NOAA track is approximately six miles to the west of the Doppler images of the eye at the landfall coordinates. These coordinates were tabulated to be the actual point of landfall of Hurricane Charley in a report written by both NOAA and the National Hurricane Center of the National Weather Service [NHC 2004]. The Doppler radar track places all of the sites (except Cherry Estates and Pine Island Cove) much closer to the storm eye wall than suggested by the NOAA

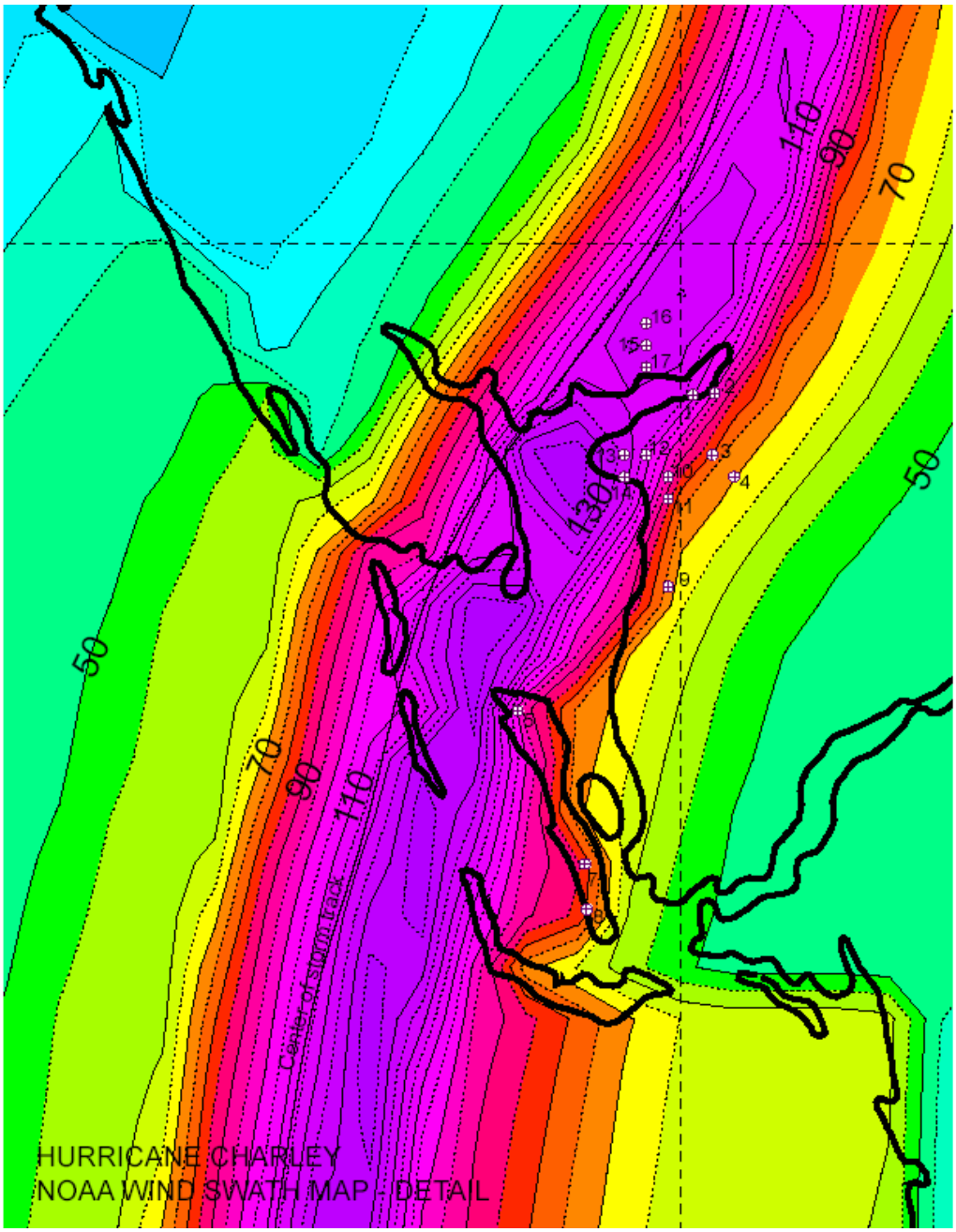
[4] Conversation with NOAA scientist, Nov. 7, 2005

[6] Fastest mile is an older representation of sustained wind speeds that is used by the ASCE standard referenced by the HUD Code. The 90 to 100 mph (1-minute, sustained) derived from the NOAA wind swath map converts to fastest mile speeds of 93 to 114 mph.

[7] http://www.aoml.noaa.gov/hrd/tcfaq/D5.html

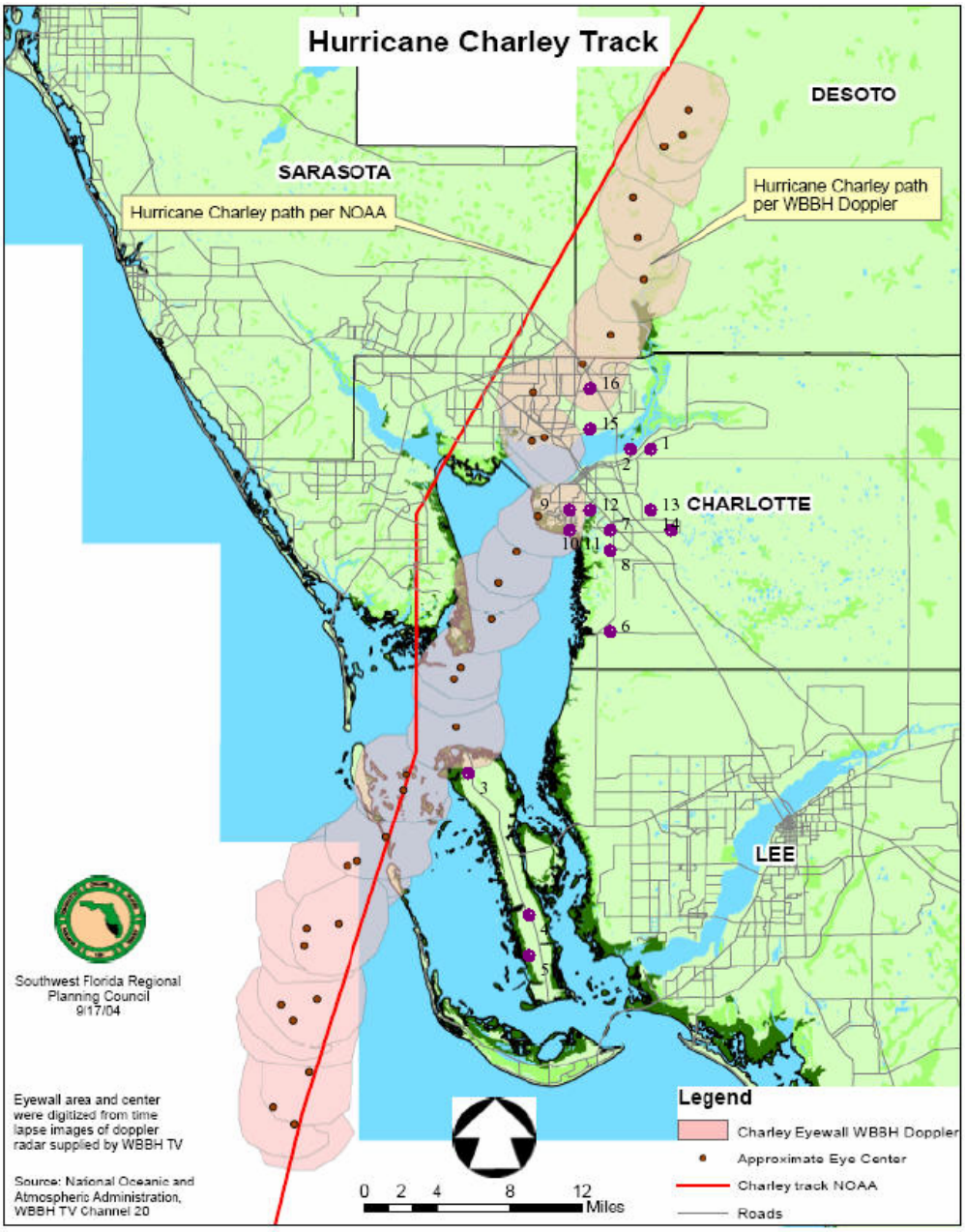
experimental wind field model. Doeden's analysis includes site-specific estimates of wind speeds using a variety of data sources.

Figure 2 NOAA wind swath map from the experimental H*Wind model



In contrast to the HUD-estimated wind speed range of 93 to 114 mph, the storm track suggested by Doeden based on the Doppler readings would have produced fastest mile wind speeds for the sites in the range of 120 to 150 miles per hour.

Figure 3 Hurricane Charley storm track based on Doppler radar



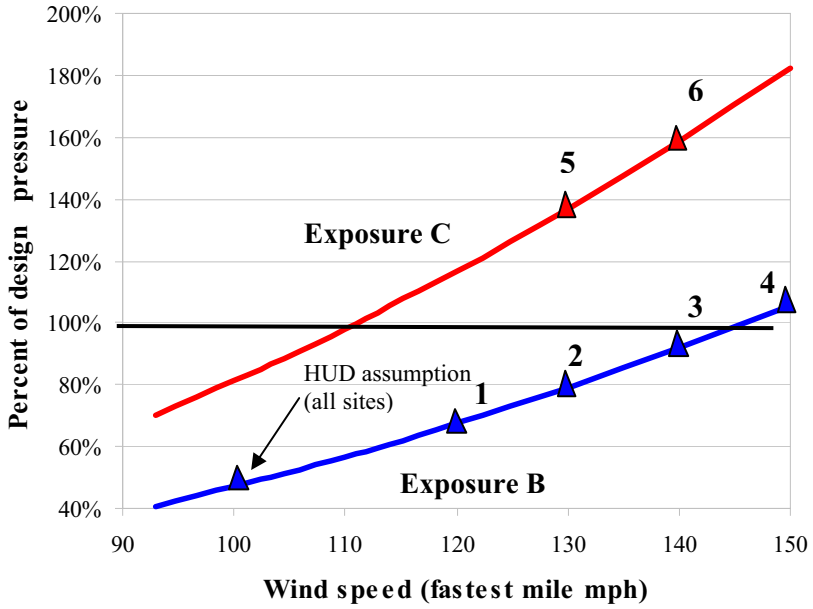
D. Summary results

Main wind force resisting system

Figure 4 provides a plot of wind speed verses percent of design pressure based on Doeden's exposure class determinations for the 16 sites (Table 1) and the Doppler weather data (Figure 3). The values are shown relative to the HUD Code design requirement (100% of design pressure), in this case for the main wind force resisting system (structure). All sites fall at one of six points on the graph. HUD's analysis assumes that the 16 sites can be characterized by a single point (100 mph wind at exposure class B), with those sites experiencing about 50% of the design pressure.

Applying the Doeden-derived data, sites classified as exposure B experienced between 69% and 108% of the design load and those in exposure C areas sustained loads in excess of design conditions, from 140% to 162% (Table 2 lists each site and the corresponding location on the graph.) A majority of the sites, 11 of the 16, lie above the 100% line for main wind force resisting systems. The Doeden analysis indicates that these 11 sites experienced conditions during Hurricane Charley that exceeded the threshold for a design event.

Figure 4 Relationship of exposure and wind speeds to design pressure for main wind force resisting system (MWFRS)



Components and cladding

Similarly, Figure 5 indicates the percent of design pressure for components and cladding for the 16 sites. Per ASCE 7, component and cladding load is calculated assuming the site is classified as exposure C, regardless of the actual terrain and shielding. Therefore, using the Doppler data, components and cladding at all 16 sites experienced pressures in excess of the design loads (119% to 186%) compared with the HUD report result estimating a single wind loading resulting in 75% of the design pressure.

Figure 5 Relationship of wind speeds to design pressure for components and cladding (C&C)

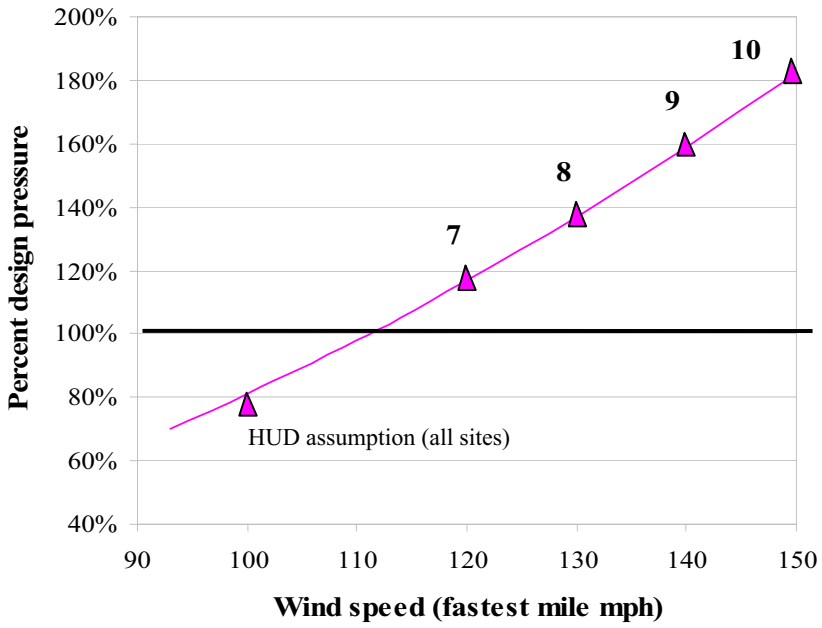


Table 2 Surveyed sites with exposure class

HUD site number	Site	Exposure class (per Doeden)	Reference points for Figure 4 and Figure 5	
			MWFRS	C&C
9	Burnt Store Colony	**C**	5	8
13	Buttonwood Village	**C**	5	8
14	By the Sea	**C**	5	8
8	Cherry Estates	**B**	1	7
17	Harbor View MHP	**C**	6	9
1	Lakewood Village	**C**	5	8
10	Park Hill	**C**	6	9
2	Pine Acres	**C**	5	8
7	Pine Island Cove	**B**	2	8
16	Port Charlotte Village	**B**	2	8
11	River Haven	**B**	3	9
4	River Oaks	**B**	2	8
14	S. Punta Gorda	**C**	5	8
5	September Estates	**B**	4	10
3	Ventura Lakes	**C**	5	8
12	Windmill MHP	**C**	6	9

Inconsistent/incorrect use of ASCE 7 importance factor

Another example of the lack of data specificity that plagues the HUD report is selection of the *importance factor* "I" used in calculating the percent of design loads experienced at the sites. The importance factor is a constant (derived from ASCE 7-1988, Table 5)

that when multiplied by the wind speed accounts for a site's distance from the ocean and for the building structural type.

In calculating the load for components and cladding, HUD effectively assumed that all sites were 100 miles inland by using an importance factor of 1.00. However, in calculating the load for the main wind force resisting systems the HUD report applies an importance factor of 1.05, effectively assuming that all sites are at the ocean line. The effect of this incorrect application of the importance factor is to slightly overestimate loads for the main wind force resisting systems and slightly underestimate loads for components and cladding (by a few percentage points for each).

The Doeden report suggests applying an interpolated importance factor of 1.04, conservatively assuming the sites are on average 20 miles inland.[8]

E. Analyzing the survey

Much of the HUD report is devoted to interpreting the surveyed damaged sustained by homes in the sample. However, missing from the author's assessment and findings, but evident from the survey results (see Table 3 for summary data), are some notable observations, such as:

- No post-1994 homes surveyed experienced structural damage to the elements of the home governed by the HUD Code. (This is particularly impressive in light of Doeden's findings that many of these sites were exposed to wind pressures in excess of the design loads.)
- Only one post-1999 home had foundation damage other than minor shifting on piers (again, according to Doeden, this home experienced loads in excess of the main wind force resisting system design load).
- Only one home built between 1994 and 1999 had foundation damage other than minor shifting on piers (similarly, this home experienced loads in excess of the main wind force resisting system design load).
- Only three of 28 pre-1994 HUD-code homes had severe damage to the home (wall or roof rating of 3). (This despite the fact that loads were in excess of post-1994 design loads for most homes and even farther in excess of the pre-1994 design loads to which the homes were built).

In addition, the statistical methods used in the HUD report to extrapolate and draw conclusions from the sample were reviewed. In question was whether the sample size was large enough to develop meaningful conclusions about the performance of the HUD-code homes and to generalize these conclusions to all HUD-code homes.

The data are only marginally useful for such an assessment. A sample size of 105 observations is typically sufficient to draw top-side conclusions on an infinitely-sized universe, but the authors admit that the sample is not meant to be representative of the stock of manufactured homes. It is therefore meaningless to provide summary statistics on all 105 observations unless the data are weighted to reflect the actual age distribution of the manufactured housing stock. No such weighting is attempted by the HUD report authors.

[8] ASCE 7-88 requires linear interpolation for I for sites between the hurricane ocean line and 100 miles inland.

Table 3 Homes surveyed by HUD sustaining damage

HUD ID		Site	HUD Damage Ratings*			Conditions at home sites[9]			
Sheet	Site		Roof	Walls	Fdn	Exposure	Wind speed (FM)	Design Load (%)	
								MWFRS	C&C
Pre-HUD Code									
9	2	Pine Acres	3	3	2	C	130	n/a	n/a
12	2	Pine Acres	3	3	2	C	130	n/a	n/a
25	12	Windmill	3	3	0	C	140	n/a	n/a
34	13	Buttonwood Village	3	3	0	C	130	n/a	n/a
45	14	S. Punta Gorda	3	3	0	C	130	n/a	n/a
47	14	S. Punta Gorda	3	3	0	C	130	n/a	n/a
49	14	S. Punta Gorda	3	3	0	C	130	n/a	n/a
51	14	S. Punta Gorda	3	3	0	C	130	n/a	n/a
31	12	Windmill	3	2	0	C	140	n/a	n/a
35	13	Buttonwood Village	3	1	0	C	130	n/a	n/a
48	14	S. Punta Gorda	2	1	0	C	130	n/a	n/a
23	5	September Estates	1	0	3	B	150	n/a	n/a
89	12	Windmill	3	2	Unk	C	140	n/a	n/a
29	12	Windmill	1	2	1	C	140	n/a	n/a
44	14	S. Punta Gorda	3	1	0	C	130	n/a	n/a
Built from 1976 through 1993									
71	2	Pine Acres	3	3	1	B	130	n/a	n/a
74	2	Pine Acres	2	2	2	C	130	n/a	n/a
39	13	Buttonwood Village	1	2	1	C	130	n/a	n/a
105	14	By the Sea	3	1	0	C	130	n/a	n/a
1	1	Lakeland Village	2	1	0	C	130	n/a	n/a
2	1	Lakeland Village	2	1	0	C	130	n/a	n/a
75	2	Pine Acres	2	1	1	C	130	n/a	n/a
91	13	Buttonwood Village	2	1	Unk	C	130	n/a	n/a
92	13	Buttonwood Village	1	1	2	C	130	n/a	n/a
80	4	Riverside Oaks	3	1	Unk	B	130	n/a	n/a
Built between 1994 and 1999									
13	**2**	**Pine Acres**	**1**	**1**	**2**	**C**	**130**	**137%**	**137%**
Post-1999									
37	**13**	**Buttonwood Village**	**1**	**1**	**3**	**C**	**130**	**137%**	**137%**

* The HUD damage ratings are assigned as follows:

- Roof: 0=no damage, 1=exterior finish damage only, 2=sheathing/gable damage, 3=partial or full roof blow-off, Unk=unknown/not available.
- Wall: 0=no damage, 1=exterior finish damage only, 2=sheathing/local damage but standing, 3=partial or full wall collapse, Unk=unknown/not available.
- Foundation: 0=no damage, 1=minor shifting apparent, 2=significant shifting but on piers and standing and/or few piers collapsed, 3=roll-over or shifted off piers, Unk=unknown/not available.

[9] Values per John Doeden, see Appendix A

Additionally, the HUD study assumes all homes in the sample were placed under the same amount of duress (50% of the HUD Code design wind load for main wind force resisting systems and 75% for components and cladding), which was undoubtedly not the case.

In summary, the conclusions of the report overstep a weak statistical foundation. The study should only be used to draw the most general conclusions about the performance of HUD-code homes during Hurricane Charley.

F. Summary of findings

The report contains what should be viewed as a rough, initial evaluation of the storm data. The authors themselves make this point in stating: "*any wind speeds reported herein should be considered as preliminary and subject to change as additional data and/or modeling results become available*." (page 10). However, the report goes on to develop conclusions about the performance of homes implying that the data and resulting analysis are final and the results conclusive. A higher standard must be met before cause and effect can be definitively established, including:

- Data about wind speeds and resulting pressures must be estimated with greater precision, thoroughly vetted and not subject to wide variation or interpretation.
- Other engineering judgments that potentially impact the results and conclusions must be approached with rigor and be consistent with the practices and views of the engineering community. This is typically accomplished through peer review.
- In making observations based on statistical analysis methods, the sample size defines the confidence level. Small sample sizes are a poor basis for suggesting patterns or drawing definitive conclusions. Conclusions based on statistical evidence intended to characterize the population of homes must be based on a sufficiently large and representative sample of homes.

None of these conditions are met by the HUD report. The data and observations contained in the report are a starting point perhaps for such analysis but are not a sufficient basis upon which to draw conclusions. The report hurries to the finding that Hurricane Charley was not a "design event," a finding that underpins many of the significant conclusions made in the report.

Applying an equally reasonable set of assumptions, and interpretation of the available storm data and reasonable judgments about the exposure class of the sites leads to a very different overall finding— for most of the homes in the survey, Hurricane Charley created conditions exceeding the wind force threshold associated with a design event. Viewed from this perspective, the tone and conclusions of the report would be quite different and suggest that homes built to contemporary standards performed well.

A consensus view that most of the homes experienced a design event would yield conclusions, such as:

- New homes (post-1994) performed well particularly given the fact that for a majority of the sites the storm exceeded design conditions. While some new homes had minor incidences of lost shingles and dents in the siding, none sustained structural damage.
- Homes built over Florida foundations survived the storm with little or no damage and only one out of the 24 post-1999 homes built over a conventional

(non-permanent) foundation sustained damage. Whether the damage that occurred was due to workmanship or design was not determined nor is the sample size sufficiently robust to suggest that changes in foundation design required in Florida after 1999 account for the improved performance of the homes under hurricane conditions.

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Contributors

This report was prepared by MHRA at the request of the Manufactured Housing Institute. MHRA is solely responsible for the report content and commentary.

Advice and insights into the engineering principles and practices that relate to the design of manufactured homes were provided by Ed Bryant, PE (Champion Enterprises), William Farish, PE (Fleetwood Enterprises) and Bert Kessler (Palm Harbor Homes). Guidance on accepted methods for conducting statistical analysis was provided by Thomas Beers, Economist (Manufactured Housing Institute). Valuable information about the Florida sites struck by Hurricane Charley and the aftermath of the storm was provided by William Turney (Florida Manufactured Housing Association). Insights into the engineering assumptions and methods for evaluating the magnitude or wind loads resulting from Hurricane Charley were provided by John Doeden, PE. At the request of MHRA, Mr. Doeden conducted an independent analysis of the sites and the storm data. His findings are contained in Appendix A. Mr. Doeden's judgments about the site exposure class were subsequently reviewed by Philip Bergelt (Bureau of Mobile Homes & RV Construction, State of Florida, SAA) and Tony Pedonisi, PE. Their statements corroborating Mr. Doeden's judgments and analysis are included in Appendix B. MHRA also acknowledges the assistance of Dr.

M. D. Powell (National Oceanic and Atmospheric Administration) in helping to clarify the use, application and limitations of wind data associated with Hurricane Charley.

Appendices

A. Report by John Doeden, PE

B. Comments on the Doeden report (Bergelt and Pedonisi)

Survey of Exposure Categories of Manufactured Home Parks in the Path of Hurricane Charley on Florida's West Coast, August 13, 2004

John Doeden, P.E.

The purpose of this survey is to determine the exposure category and approximate wind speed of the various manufactured home sites that were in the path of Hurricane Charley or in close proximity near its point of landfall in Lee and Charlotte Counties in Florida. In response to a request from the Manufactured Housing Research Alliance, this survey provides an assessment of the design event conditions at sixteen manufactured housing communities in those counties through the duration of the storm, based on the two factors that determine the design wind pressure; 1) the extent to which the community sites are exposed to the wind (exposure category B or C as defined by ASCE 7-88) and 2) the magnitude of the winds that characterized the hurricane at each one of those sites. These factors are discussed in the commentary that follows.

The exposure category of each site in this assessment is determined by 1) on-site observations, 2) the study of pre-hurricane Charley aerial maps of both Lee and Charlotte counties, 3) aerial survey of the direction objects were displaced in the storm, 4) the relation of the site to the position of the eye and, 5) in some cases, polling residents of an individual site about the terrain at the time of landfall. This report also provides a thorough analysis of the wind speed at each site, since hurricane wind speed can vary substantially in short distances beyond the eye wall.

It should be noted that all sites visited were in the path of the eye wall and/or the right front quadrant of the hurricane, which produces the most intense wind speeds due to the forward land speed of the storm. Figure 1 tracks the forward progress of the eye and eye wall as it moves inland. September Estates, Windmill, Buttonwood Village, S.Punta Gorda/ By the Sea, Port Charlotte Village, and Harbor View were closest to the right eye wall and, except for Harbor View, were *in* the six-mile wide eye. Port Charlotte Village and Harbor View were not visited, but aerial maps indicate the exposure in the direction of wind. For those sites over which the eye directly passed there may exist more than one exposure category, due to the opposing directions of wind. This is depicted in the aerial survey of displaced objects. The table summarizing the findings indicates the direction of wind at the various sites and the corresponding exposure, based on data available on the track of the eye and the aerial surveys.

For determining the exposure category the 1988 version of the ASCE 7 is used, because this standard is referenced in the Federal Manufactured Home Construction and Safety Standards in effect at the time of Hurricane Charley. Exposure B was assigned when the definition from ASCE 7-88 was met in the windward direction during the storm; "urban or suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger. Use of this exposure category shall be limited to those areas for which terrain representative of Exposure B prevails in the upwind direction for a distance of 1500 feet". When it was not apparent whether exposure B terrain "prevailed" for 1500 feet, the more conservative assignment

was made, which is exposure B for the purpose of this report. Exposure C was assigned when its definition was met in the windward direction; "open terrain with scattered obstructions having heights generally less than 30 feet." Verification of these definitions was made and also described in the table corresponding to each site and exposure.

Hurricane Charley produced design event winds for main wind force resisting systems in at least 11 of the 16 sites surveyed, even though some of these sites were classified in this survey as exposure B. Components and cladding received design event pressures for all sites surveyed. The maximum 1-minute sustained wind speed was estimated to be in the range of 140 to 145 mph at the time of landfall in Punta Gorda (Ref. #3), which translates into fastest mile at 153 to 158 mph. The anemometer at the Port Charlotte airport was of no value in substantiating peak gusts, since it failed prior to the maximum reading. However, two accounts (ref. 6 & 7) noted a gust of 172 mph or more in Punta Gorda, which correlates closely with the 1-minute sustained wind speed reported.

The wind speeds at each site were conservatively estimated based on the distance of the site from the eye and the distance inland of the hurricane, although it should be noted that this hurricane maintained its intensity many miles inland (sustained winds were 105 mph when it reached Polk County at least 50 miles from landfall in Punta Gorda). Hurricane Charley's maximum winds were estimated to have been seen a distance of seven miles from the center of the eye (Ref. 5). The site furthest from the center was Cherry Estates, approximately 12 miles and Pine Island Cove, approximately 10 miles from the center. These were the only sites in the sample that were beyond the seven miles maximum wind radius. The remaining 14 sites were within the maximum wind radius of seven miles. The sustained wind speed was reported to have been 150 mph (163 mph fastest mile) at 82.2 degree longitude/26.6 degree latitude in the area of September Estates, Pine Island Cove, and Cherry Estates and 144 mph (155 mph fastest mile) at 82.1 degree longitude/26.9 degree latitude in the area of Windmill, Buttonwood Village, and S.Punta Gorda/ By the Sea. It should be noted that the inland terrain is considered to consist of similar roughness patterns as the open water churning in the wind of the hurricane and, therefore, the wind speed would not be expected to significantly diminish inland within the seven miles radius. Nevertheless, to be conservative the wind speed was assigned to be 130 mph at the periphery sites of Lakewood Village, Pine Acres, Burnt Store Colony, Ventura Lakes, and River Oaks, not the 155 mph (fastest mile) reported for the maximum. Also, the sites in the direct path of the eye, such as Buttonwood Village, By The Sea, and Port Charlotte Village, were assigned 130 mph, since they would not have seen Charley's relative land speed of more than 20 mph, but rather, only the speed of the wind at the eye wall.

The track of the hurricane was taken from the Doppler radar images, which closely coincides with the HAZUS-MH wind methodology determined to be the most accurate track (ref. 6), rather than the track modeled by NOAA (ref. 6). See Figure 1 showing both the Doppler and the NOAA tracks. As can be seen in this map, the NOAA track is approximately six miles to the west of the Doppler images of the eye at the landfall coordinates. These coordinates were tabulated to be the actual point of landfall of Hurricane Charley in a report written by both NOAA and the National Hurricane Center of the National Weather Service (Ref. 3). This discrepancy in the actual Doppler radar

track and the NOAA model puts all of the sites (except Cherry Estates and Pine Island Cove) much closer to the eye wall than suggested by the NOAA experimental wind field model.

The percentage of the design load for the units installed at each site was determined from pressure formulas in the ASCE 7-88 standard for wind. The components and cladding (c & c) formulas are different from the main wind force resisting system (MWFRS) formulas. Per Table 4 of ASCE 7-88 the c & c pressures are to be determined for exposure C, regardless of the terrain. However, since some of the sites are several miles from the "hurricane oceanline" (includes the Gulf of Mexico), linear interpolation of the importance factor, I, is required per ASCE 7-88. The interpolated result, assuming conservatively that all sites are 20 miles from the hurricane oceanline, is (actual wind x 1.04) ^{2} / (design wind x 1.05) ^{2}. This reduces to (actual wind) ^{2}/ 12,334. As can be seen in Table 1, when applying this reduction factor to the c & c load column, the resulting percentage of design event loads exceeds 100 for all sites surveyed.

The MWFRS pressure comparison in percent from exposure C to B includes the reduction in the importance factor I of 1.04 vs. 1.05 and the difference in the velocity pressure exposure coefficient, Kz, and the gust response factor, Gh. The percentage formula then becomes (1.65/ 1.32) x (0.37/ 0.8) x (actual wind x 1.04) ^{2} / (110 x 1.05) ^{2} = (actual wind) ^{2} / 21,334. For C exposures the percentage is (actual wind) ^{2} / 12,334. The design event load percentage for MWFRS loading exceeded 100 in all sites, except five (Pine Island Cove, Cherry Estates, River Haven, River Oaks, and Port Charlotte Village).

It is interesting to note that other reports (e.g. ref. 4 and 6) indicated that Charley was a design event or greater when comparing it to design pressures based on the 2001 Florida Building Code. Those design pressures for 130 mph (3 second gusts) are not significantly different from those of ASCE 7-88 for the equivalent speed of 110 mph (fastest mile) for both c & c and MWFRS loading. Both Port Charlotte and Punta Gorda are in the 130 mph (3 second Gust) region of the Florida wind map.

References:

1. Southwest Florida Regional Planning Council, Hurricane Charley Map
2. Post Storm Data Acquisition Aerial Wind Mapping Mission- Hurricane Charley-2004, NOAA & The National Weather Service, Oct. 25, 2004
3. Tropical Cyclone Report- Hurricane Charley 9-14 August 2004, National Hurricane Center, 18Oct2004 (Revised 5Jan2005)
4. Preliminary Damage Observations- Hurricanes Charley, Frances & Ivan, 2004, Institute for Business & Home Safety.
5. Estimating Surface Wind Fields in Tropical Cyclones Using Infrared Imagery, Jim Kossin, Univ. of Wisconsin, SSEC, presented March 2005 at the Interdepartmental Hurricane Conference, Jacksonville, FL
6. Executive Summary, Hurricane Charley in Florida, Mitigation Assessment Team Report, August 19,2004, FEMA Mitigation Div.

7. Hurricane Charley – Storm History, Wikipedia
8. ANSI/ASCE 7-88, Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers, 1988, ANSI approved Nov. 27, 1990.

Table - Exposure Categories of Sixteen Sites Assessed in order Visited

Site Number	Site Name and Reference	Relation of Site to Eye	Direction of Wind	Description of Terrain	Exposure Category	Wind Speed (3) (Fast.Mile)	Resulting % of Design Load	
							c & c	MWFRS
1	Pine Acres Bernadean Blvd ccgis.com	RF Quad RR Quad	NNW & N N & NNE	Open South Houses SW	C B	130 mph	137% 137%	137% 79%
2	Lakewood Village ccgis.com	RF Quad RR Quad	NNW & N N & NNE	Subdevelopment South but no houses, few trees	B & C C	130 mph	137% 137%	79- 137% 137%
3	September Estates Buzzard Crt leepa.org	RF Quad Eye RR Quad	W & NNW n/a E	Mature pines SW Trailer Park South	B B	150 mph	182% 182%	105% 105%
4	Pine Island Cove leepa.org	RF Quad RR Quad	NNW & N N & NNE	Mature scrub pines South & SW	B B	130 mph	137% 137%	79% 79%
5	Cherry Estates Sloop Lane leepa.org	RF Quad RR Quad	NNW & N N & NNE	Mature scrub pines South & SW	B B	120 mph	117% 117%	68% 68%
6	Burnt Store Colony Colony Pkwy ccgis.com	RF Quad RR Quad	NE NW	Subdevelopment South but no houses & No trees	C C	130 mph	137% 137%	137% 137%
7	Park Hill ccgis.com	RF Quad RR Quad	NNW ENE	Scattered objects less than 30' high	C B	140 mph	159% 159%	159% 92%
8	River Haven ccgis.com	RF Quad RR Quad	NNW ENE	Mature pines S & SW	B B	140 mph	159% 159%	92% 92%
9	Buttonwood Village ccgis.com (2, 3)	RF Quad Eye RR Quad	WNW n/a ESE	Scattered scrub < 50% lots w/o houses ~ 50% terrain-canals	B C	130 mph	137% 137%	79% 137%
10	S. Punta Gorda (2, 3) Almar Dr ccgis.com	RF Quad Eye RR Quad	WNW n/a ENE	< 50% lots w/o houses ~ 50% terrain-canals Beyond is scrub & bay	C C	130 mph	137% 137%	137% 137%
11	By The Sea (2, 3) River Bay Drive ccgis.com	RF Quad Eye RR Quad	WNW n/a ENE	< 50% lots w/o houses ~ 50% terrain-canals Beyond is scrub & bay	C C	130 mph	137% 137%	137% 137%
12	Windmill MHP ccgis.com	RF Quad Eyewall RR Quad	NW N E	< 50% lots w/o houses ~ 50% terrain-canals Scattered scrub	C C C	140 mph	159% 159% 159%	159% 159% 159%
13	Ventura Lakes ccgis.com	RF Quad RR Quad	NNW NNE	Open grassland S & SW	B & C C	130 mph	137% 137%	79- 137% 137%
14	River Oaks ccgis.com	RF Quad RR Quad	NNW NNE	Mature pines S & SW	B B	130 mph	137% 137%	79% 79%
15	Harbor View MHP ccgis.com (1)	RF Quad Eyewall RR Quad	NW N NE	Charlotte Bay SW,S, SE	C C C	140 mph	159% 159% 159%	159% 159% 159%
16	Port Charlotte Village ccgis.com (1)	RF Quad Eye RR Quad	WSW n/a ESE	Subdevelopments SW & South	B B	130 mph	137% 137%	79% 79%

(1) Sites not visited. Assessed by Pre-Charley aerial survey.
(2) Sites 9 & 10 were in the direct path of Charley - therefore did NOT see the 20 mph forward travel speed.
Resultant Wind Speed = 144 mph reported at landfall - 20 mph = 124 mph (sustained)= 132 mph (Fast.Mile).
(3) Speeds tabulated are assumed for both the forward side of the eye and the backside, due to an insignificant weakening as Charley moved inland.

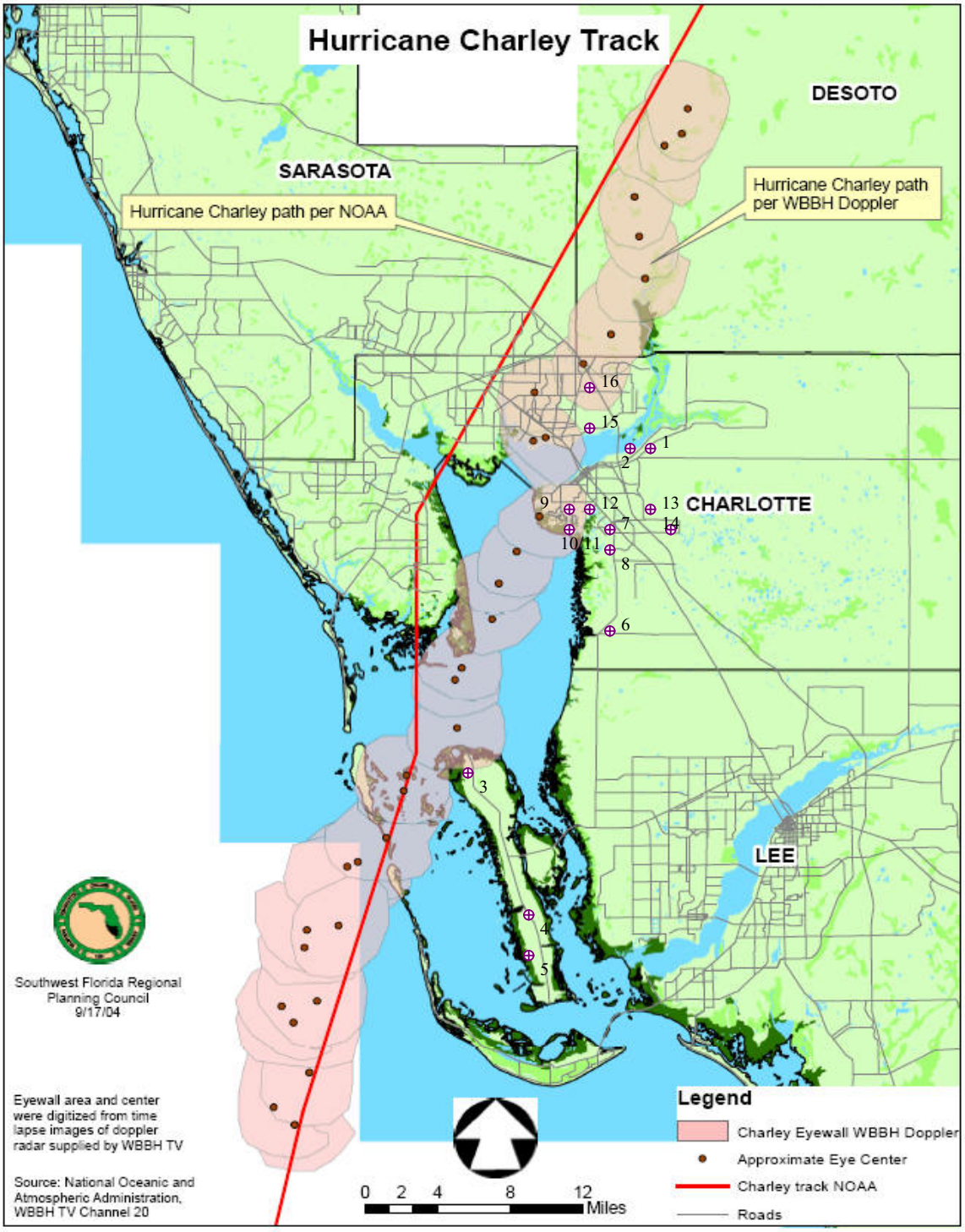

Figure 1: Track of Hurricane Charley's Eyewall in Lee & Charlotte Counties

Pre-Charley Aerial View from Charlotte County Web Site: www.ccgis.com/gis/MapFrame

Figure 2.0: Ventura Lakes – Exposure C. Arrows indicate direction of maximum wind over Exposure C terrain.

Pre-Charley Aerial View from Charlotte County Web Site;
www.ccgis.com/gis/MapFrame

Figure 2.1: Burnt Store Colony- Exposure C approximately 6-1/2 miles from center of eye. Arrow indicates direction of maximum wind (NNE)

Pre-Charley Aerial View from Charlotte County Web Site: www.ccgis.com/gis/MapFrame

Figure 2.2 : Buttonwood Village – Exposure C for easterly wind direction bottom side of eyewall. Turquoise arrow Indicates direction of maximum wind for Exposure C terrain

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Pre-Charley Aerial View from Charlotte County Web Site;
www.ccgis.com/gis/MapFrame

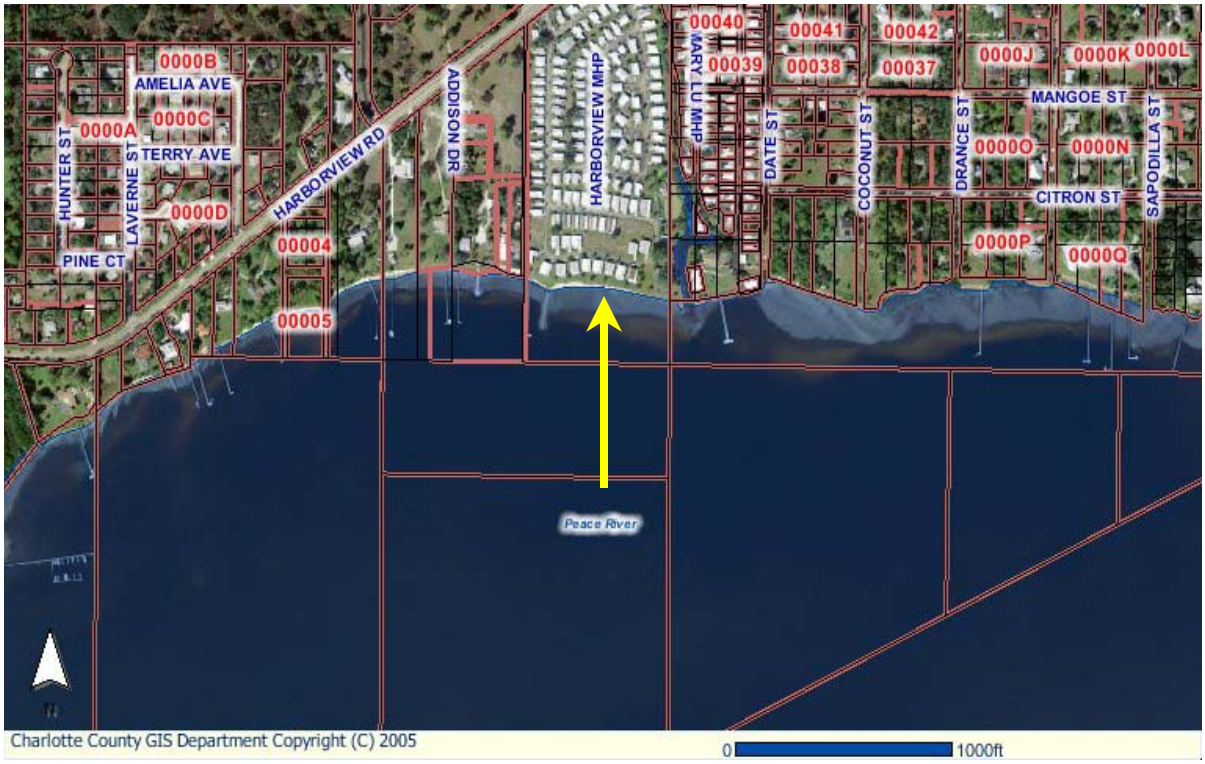

Figure 2.3: Harbor View MHP – Exposure C approx. 500 feet from right eyewall. Arrow indicates direction of maximum wind (North).

Comment by Mr. Phil Bergelt on the analysis by John Doeden, PE

Mr. Phil Bergelt, Manufactured Housing Installation Manager, Department of Motor Vehicles, State of Florida, was asked to review and comment on the analysis by John Doeden (Appendix A of this report). In response, Mr. Bergelt issued the following statement:

> ***"I have reviewed The Institute of Building Technology (HUD) report on Hurricane Charley and the John Doeden, P. E., report. I find the Doeden report with the Doppler Track and statements made as to exposure categories to be much more in line with my personal observations in August 2004. Thanks, Phil Bergelt"***

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February 7, 2006

Mr. William Turney
Assistant Executive Director
170 31st Ave.
St. Petersburg Beach, FL 33706

Re: Review of Report Authored by John Doeden, P.E. Titled: "Survey of Exposure Categories of Manufactured Home Parks in the Path of Hurricane Charley on Florida's West Coat, August 13, 2004"

Dear Mr. Turney:

At your request I have reviewed the subject report for the purpose of determining if the information contained, therein, is valid and the conclusions drawn in the report are accurate. After review of the report and drawing upon my knowledge and experience of the area, I am in general agreement with the findings of the report and specifically with the **exposure category** and **approximate wind speeds** that are summarized in the Table on page 5 in the report.

I am familiar with the storm area in the path of Hurricane Charlie and had previously toured the storm area after the storm event and found that the assignments made by Mr. Doeden for Exposure B, in the windward direction of the storm; "Urban or suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger", and Exposure C, "Open terrain with scattered obstructions having heights generally less than 30 feet" to be true and accurate in those areas selected in the table of page 5 of the report.

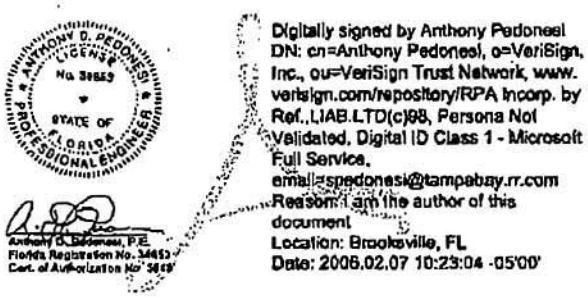
Charlotte County is basically composed of one story structures with those more than one story being relatively rare. In my opinion, Exposure C as shown in the table of page 5 is a reasonable assessment of the terrain conditions. Also Exposure B for the remainder of Hurricane Charley's path provide a more conservative assessment for purposes of storm damage.

In addition, I found the wind speeds to be reasonable in light of general agreement that that Hurricane Charley's central pressure at or near the time of landfall provided wind speeds estimated to be 141 mph (See Reference 1). Further, per Mr. Doeden's report, "sustained winds of 105 mph were reached in Polk County at least 50 miles from landfall in Punta Gorda". With this statement, the wind speeds of the table on page 5 of Mr. Doeden's report are reasonable.

In summary, my review of the report by John Doeden, P.E summarizing the exposure categories and approximate wind speeds are reasonable and justifiable with the given references contained within his report.

It is my pleasure to review this work for you and I am available for additional summarizing of my findings.

Best regards,



Ref1 – Hurricane Charley 1930 UTC 13 Aug 2004, Observed Max Surface Wind, NOAA/AOML/Hurricane Research Division.