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Effects of Hurricane Harvey and Irma on State Building Codes

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01. Introduction

In the United States, both engineers and contractors are held to building codes to ensure infrastructure completes its useful lifetime. This includes designing structures to withstand assumed loads, exposure to the wind and rain in addition to common wear and tear, as well as building it using proper means and methods. If these codes are adhered to, a building should stand through its service life, roads should remain intact and smooth and bridges should span across great lengths uninterrupted. Because of America's diverse landscape, each state has adopted its own building specifications to design against common issues in the region. Plain states will see higher winds, the West Coast must guard against earthquakes and the Southeast region worries about hurricanes, just to name a few examples. These specific codes are in place to design against the most probable disaster, not the worst-case scenarios. However, it seems that the most probable case is slowly getting worse, and our specifications are quickly becoming inadequate preparations for what nature is throwing at us.

The year 2017 put coastal building specifications to the test. According to the National Oceanic and Atmospheric Administration (NOAA), it was the most active hurricane season in over a decade; of the 17 storms large enough to be assigned names, six of them became hurricanes greater than a category three.[1] Two of these storms made landfall in the U.S. back to back, Hurricanes Harvey and Irma. Hurricane Harvey made landfall in Texas, flooding much of Houston and the surrounding areas. Hurricane Irma first strafed the Caribbean then made its way up Florida leaving in its wake damage not seen Hurricane Wilma in 2005. While both states have codes put in place to withstand the forces of hurricanes, they seemed many structures were still destroyed. Was this an atypical year for aggressive hurricanes, or were the specifications falling behind what will become the norm?

02. Background

Hurricane Harvey made landfall just North of Corpus Christi, Texas on August 25th. It made landfall as a category four but was downgraded after a day to a tropical storm. Hurricanes as intense as Harvey rarely make landfall in Texas, but it is not impossible. What made it particularly devastating was the massive amount of flooding incurred. Typically, as a storm or hurricane makes landfall it continues inland until much of its energy is dissipated. Harvey, however, stalled over Southeastern Texas. This did not stop it from dumping what some experts estimate to be 51 inches of rain in some locations, as well as achieving 134 miles per hour sustained winds.[2] This rainfall along with massive storm surge created flashfloods and sustained flooding throughout much of the state. The storm surge varied wildly, ranging from three feet above ground level to up to 12 feet above ground level at its peak.[3] It is estimated that 30,000 people were displaced from their homes.[2] The tropical storm would later circle back over the Gulf of Mexico and make landfall once again near the Texas-Louisiana border.

Hurricane Irma started its path of destruction as a tropical storm over the Caribbean Islands. Puerto Rico took the brunt of the storm, devastating the infrastructure of the small island. Irma then pushed on through the Florida Keys, eventually making landfall in Florida on September 10th. It struck as a category four, setting records for intensity with its windspeeds clocking in at 185 miles per hour sustained for 37 hours straight[5]. After making landfall at the southern tip of Florida, it continued straight up the center of the state, finally fizzling out over

Georgia. The storm surge produced varied by location, but places such as Naples saw up to seven feet of surge; the Keys saw up to 10 feet[6]. As violent of a storm as Irma was, the rainfall achieved was relatively low for storms of its size. The most rainfall reported came from Fort Pierce on Florida's east coast at 16 inches, a drop in the bucket to Harvey's 51 inches[7]. Irma has been documented as the most intense storm to make landfall in Florida since 2004[6].

Hurricanes Harvey and Irma hit with less than a week of time in between. While both category four hurricanes, they brought two distinctly different problems to the places they devastated. Harvey brought unprecedented flooding to Texas, most notably Houston. A high storm surge coupled with record breaking rainfall amounts lead to widespread destruction of homes and businesses. With storm surges measured around 12 feet, that is enough to cover the first floor of most buildings. Once the rainfall is included, some coastal areas experienced second floor flooding as well. Flooding was the chief cause of damage to infrastructure from Hurricane Harvey. This contrasts Hurricane Irma, where the damage was incurred by its high sustained winds. Irma's storm surge was only a few feet under Harvey, but it lacked the massive amounts of rainfall. Irma dumped less than one third of the rain experienced by areas effected by Harvey. It did so, however, with windspeeds not experienced in decades. At times, as much as 70,000 square miles were experiencing Irma's storm force winds[7]. As a comparison, at its peak 28,000 square miles around Houston experienced major flooding[7]. Both storms caused a crisis and evacuations, leaving hundreds of thousands without homes. Each brings unique challenges to building designers in the region. A concise comparison of Harvey and Irma can be found in *Table 1* in the appendix.

03. Irma and Florida State Building Code

Having a long history combating hurricanes, Florida's building code is set up to protect against hurricanes based on multiple factors. Florida establishes risks based primarily on building location and occupancy type. This creates a baseline for likeliness of damage to occur and loss of life associated if this damage were to cause the structure to fail. When analyzing building types, the code splits buildings into four primary categories:

I. *Buildings that represent low risk to human life; i.e. agricultural facilities, minor storage facilities and screen enclosures*

II. *Buildings and other structures not covered in categories I, III and IV*

III. *Buildings that represent substantial hazard to human life; i.e. buildings that are primarily used for public assembly with greater than 300 people, primary and secondary education facilities and civil infrastructure such as power generation and water treatment plants*

IV. *Buildings that are designated essential facilities; i.e. emergency treatment facilities with surgery capabilities, emergency response facilities, aviation control infrastructure and buildings critical to national defense function*[9]

The full text and descriptions can be found in Table 2 in the appendix. Categorizing infrastructure like this gives certain buildings priority over others, offering more stringent design specifications for buildings that would be detrimental to lose. The second consideration is what wind zone the building falls into geographically. Florida has these wind zones set up based on proximity to the coast and typical observed windspeeds during hurricanes. They are split up into four general zones based on ultimate design wind speeds, V_{ULT}:

1. V_{ULT} greater than 130 mph but less than 140 mph
2. V_{ULT} greater than 140 mph but less than 150 mph and greater than one mile from the coast
3. V_{ULT} greater than 150 mph and less than 170 mph or greater than 140 and less than 170 and less than one mile from the coast
4. V_{ULT} greater than 170 mph[10]

These wind zones are shown as Figures 1 and 2 in the appendix, laid out geographically and associated with building category. Listed above are specifically for Category II and Category III buildings without surgical healthcare capabilities. Buildings that fall into Category III with surgical healthcare capabilities and Category IV buildings increase V_{ULT} by 10 to 20 mph based on proximity to the coast and increases the number of wind zone gradations. This puts these buildings into higher design specification criteria. While there are other smaller specifications for what can and cannot go into buildings, wind zones and building type dictate most of Florida Building Code regarding hurricane design.

A hurricane with the magnitude of Irma will challenge any building, regardless of the codes it is built to. However, higher category buildings could be expected to fare better than those of a lower category. Analyzing each category case by case, one can determine if the building codes are adequate. The lowest category, Category I structures, will be neglected in the analysis due to its extremely low probability of loss of life and high chance of structural failure or critical damage.

The lowest category to be studied are Category II structures. Arguably, these types of structures were devastated the most by Irma. Category II structures are anything not specifically covered in the other three categories. This includes houses, mobile homes, stores and other low-occupancy structures. What separates Category I from II is the risk to human life associated with the structure. If the primary purpose of the structure is occupancy or business, and the occupancy does not exceed 300, it is a Category II structure. The Florida Keys, where Irma passed over with the highest intensity, suffered major damage. Per FEMA estimates, 90% of homes were damaged in the storm, with 25% of homes totally destroyed[12]. The Keys are in a zone where Category II structures can expect to experience 180 miles per hour windspeeds and should be built as such[11]. The basic windspeed is noted at 140 miles per hour[11]. When it made landfall in Key West, Irma had windspeeds of 130 miles per hour, sustained[13]. Looking at the observed windspeeds and going by the Florida Building Code, most buildings should have survived accruing some minor damage. Buildings like the one pictured above are common in the Florida Keys, where the high wind speeds coupled with a sharp drop in pressure sheared off the walls of this house. Roof damage was common throughout Florida, being the

Destruction present in typical Category II building in the Florida Keys after Hurricane Irma. The wall of this home was completely sheared off by the high wind speeds[12].

major source of damage observed in the FEMA estimate[12]. Destruction of Category II structures is what made Irma such a devastating hurricane for most people as it displaced many from their homes.

Category III and IV structures are buildings that pose a significant threat to human life should they fail. This includes certain healthcare facilities and buildings whose occupancy regularly exceeds 300 people. This would include large businesses, schools and medical facilities where people regularly assemble. What separates III from IV, specifically for medical facilities, is surgical capacity. Category IV structures are those able to provide surgery or structures supporting surgical facilities. One such instance was the Baptist Health's Fisherman's Community Hospital. Situated in the Florida Keys, one of the areas hit hardest by Irma, it provided local healthcare to the central Keys. Patients in need of surgery, however, were flown into Baptist Health's South Florida branch. This puts it in Category III, which in the Keys is supposed to withstand 180 miles-per-hour windspeeds[11]. The roof of the structure was destroyed, and Baptist Health is now operating out of tents after seeing sustained winds of just 130 miles per hour[14].

However, out of all the Category III and IV structures in the path of hurricane Irma, very few fared as poorly as Baptist Health. According to analysis done at The University of Hawaii, it was the only hospital to be closed longer than seven days[15]. While more than 20 facilities directly hit by Irma saw some form of loss of use time, all but Fisherman's Hospital reopened after less than 7 days[15]. This is significant because this shows that nearly all of Category III and IV buildings withstood the brunt of Irma and were reopened shortly after Irma passed. It is also difficult to determine whether these loss of use times were directly attributed to structure failures or simply just precautionary evacuation measures but given the duration it is unlikely structural.

Analyzing the impacts of Hurricane Irma on the state of Florida, it is clear that the critical infrastructure was maintained. That being said, the largest impact of Irma was on Florida's civilian population. Of all structures effected, Category II made up the bulk of those destroyed or damaged. Category III and IV structures saw some significant damages but maintained their usability even if they experienced some loss of use time. This shows that category III and IV building codes seem to be effective in safe-guarding against most hurricane damage, with very few exceptions. Buildings that were directly in the path of Irma were able to stay standing and maintain their function. Category II buildings were devastated, mostly because Irma was such an intense hurricane. Irma displayed some of the strongest sustained winds observed in over a decade, and it would be impractical to design all Category II structures to combat this type of extreme event. Additionally, portions of damage to Category II structures comes from flooding, which is not addressed in the building code categorization procedure; the building codes are primarily used to combat against high wind speeds. Because it is difficult to split the FEMA damage estimates into flooding versus wind damage categories, it is hard to establish how many Category II structures could have been preserved had the building code protected against higher wind speeds.

04. Harvey and Texas State Building Codes

Florida withstood the impact from Irma and is still rebuilding. It will be many years before everything is as it once was. Even as a region that is used to bearing the brunt of a hurricane season, Florida was hit quite hard. It has a long-standing history of extreme weather and has building codes to suite. Texas, on the other hand, does not immediately come to mind as hurricane-prone. Texas is in a region that is not under a great threat from hurricanes. As a result, Texas building codes are incredibly lax when it comes to protecting against hurricane force winds. In fact, Texas does not mandate a state-wide building code[16]. Texas only recommends that if a county wants to adopt a building code, it must be complaint to either the International Building Code (IBC) or International Residential Code (IRC), depending on the use of the structure. While both IBC and IRC incorporate flood-resistant code sections, Harris County did not mandate either be followed[17]. This makes it incredibly prone to water damage in areas that are affected. In addition to lax flood requirements, the hurricane requirements are almost non-existent. According to the Texas Minimum Construction Requirements, "…the housing must be improved to mitigate the impact of potential disasters (e.g., earthquake, hurricanes, flooding, and wildfires) in accordance with State and local codes, ordinances, and requirements."[18]. This standard is incredibly lax in regard to protecting against hurricanes, essentially only bringing up the issue if the inspection deems an area deficient. This leads to a region that is terribly under-protected against many natural disasters.

Harvey caused massive amounts of flooding across the state, causing major private property losses. However, it effected major institutions too. Texas's hospitals were hit hard with an influx of people seeking shelter and medical help. In a report done by the Texas Hospital Association (THA), the majority of hospitals were unprepared to receive this major spike in patients[19]. They were also ill-prepared to move critical care patients or those that required more intense care[19]. The THA gave recommendations to better plan for events like this if they were to happen in the future. Also according to the THA, Harvey closed down 20 different hospitals either due to flooding or power loss[19]. In comparison to the number of hospitals across the state of Texas, this is not a large amount of hospitals. However, when you look at the amount of hospitals that were closed in the proximity of Houston compared to the number of hospitals in the county, this is quite devastating. This lack of available care facilities combined with a large influx of people seeking care and shelter put incredible strain on hospitals in the area. It is possible that a universal building code in Texas could protect against most scenarios of flooding, but it is unlikely that a standardized set of codes could have stopped the flooding and failure of these hospitals.

In the aftermath of Harvey, Texas plans to implement more flood protection infrastructure. Included in this are improved reservoirs and a new dike designed to stop the higher interval-rate floods[20]. Two of the reservoirs used to temporarily restrain flood waters have been deemed "high-risk" by the Army Corps. Of Engineers[20]. These structures pose a great risk of large loss of life or property and should be addressed immediately. The new dike would be used to buffer against the amount of rain required to create a flooding situation.

Although Texas has minimum building requirements and the option to adopt a building code, it is hard to incorporate any sort of counter measures to what Harvey unleashed. Hurricane Harvey was such a freak accident that it is almost impossible to adopt any sort of construction standard to mitigate the losses against over 50 inches of rain in a single event. Without living underground or in bunkers, it is impossible to stop the damage. The amount of rain seen in Texas was incredibly abnormal, and most locations are not designed to safeguard against the high-end outlier storms. This was evident in Texas as homes and businesses were damaged beyond repair in one of the worst flooding events to happen in Texas in recent history.

05. Analysis and Conlusion

In areas that are prone to hurricanes, building codes are a necessity. In the southwest region, Florida being the case study, it was shown that buildings built to higher code standards faired better than those that were in lesser categories. This is crucial to the well-being of the region, as the buildings that are built to these higher standards are the most important- hospitals, military installations, and large gathering places that pose a high risk to large amounts of casualties. Being hit with hurricanes year after year, Florida has adapted its building code to protect its critical infrastructure. While loss of private property, especially people's homes, is a terrible loss, it is not cost effective to build every home to resist a category five hurricane. Florida's prime area of protection was safe-guarded due to its strict building codes.

Texas on the other hand experienced a large loss of personal property and saw many hospitals close. While these issues cannot be directly tied to the lax building codes present in these hurricane regions, it can be argued that implementation of basic codes could have prevented some of the panic and closures. Houston experienced a loss of the majority of its hospitals and went into a crisis. Massive amounts of people went to these places to seek shelter only to find they were not able to house the patients currently check in, let alone thousands more. Standardized building codes could have prevented some power outages by mandating utility locations or generator fortifications. However, the flooding experienced during Hurricane Harvey would have rendered these codes a moot point.

In the two states analyzed studying two hurricanes of the same magnitude, it was shown that the state with minimum building codes faired better. Florida's codes protected it's critical infrastructure and maintained a sense of control despite having a handful of hospitals shut down. The hospitals that did shut down only experienced a few loss of days, with the exception of one hospital that was permanently closed in the Florida Keys. Texas, having no standardized minimum building codes, experienced major shut downs to its healthcare infrastructure and personal property. This goes to show that a set of building codes, particularly one catered to defend against hurricanes, is extremely effective in safeguarding against critical infrastructure damage.

Appendix

Table 1- Comparing Harvey and Irma in intensity using common parameters in assigning hurricane category.

Hurricane	Category	Windspeeds	Rainfall	Pressure	Storm Surge
Harvey	4	134 mph (sustained)	51"	938 millibars[4]	Up to 12'
Irma	4	185 mph (sustained)	16"	915 millibars[8]	Up to 10'

Table 2- Building categories from Florida's Building Code handbook, "Table 1604.5- Occupancy Category of Buildings and Other Structures."[9]

Category	Description
I	**Buildings and other structures that represent a low hazard to human life in the event of failure, including but not limited to:** • Agricultural facilities. • Certain temporary facilities. • Minor storage facilities. • Screen enclosures.
II	**Buildings and other structures except those listed in Risk Categories I, III and IV.**
III	**Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to:** • Buildings and other structures whose primary occupancy is public assembly with an occupant load greater than 300. • Buildings and other structures containing elementary school, secondary school or day care facilities with an occupant load greater than 250. • Buildings and other structures containing adult education facilities, such as colleges and universities, with an occupant load greater than 500. • Group I-2 occupancies with an occupant load of 50 or more resident patients but not having surgery or emergency treatment facilities. • Group I-3 occupancies. • Any other occupancy with an occupant load greater than 5,000. (a) • Power-generating stations, water treatment facilities for potable water, waste water treatment facilities and other public utility facilities not included in Risk Category IV. • Buildings and other structures not included in Risk Category IV containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released.

IV	**Buildings and other structures designated as essential facilities, including but not limited to:** • Group I-2 occupancies having surgery or emergency treatment facilities. • Fire, rescue, ambulance and police stations and emergency vehicle garages. • Designated earthquake, hurricane or other emergency shelters. • • Designated emergency preparedness, communications and operations centers and other facilities required for emergency response. • Power-generating stations and other public utility facilities required as emergency backup facilities for Risk Category IV structures. • Structures containing highly toxic materials as defined by Section 307 where the quantity of the material exceeds the maximum allowable quantities of Table 307.1(2). • Aviation control towers, air traffic control centers and emergency aircraft hangars. • Buildings and other structures having critical national defense functions. • Water storage facilities and pump structures required to maintain water pressure for fire suppression.

Figure 1- Design wind speeds in Florida for Category II and Category III buildings without surgical healthcare after the 2010 revision to the Florida Building Code[11].

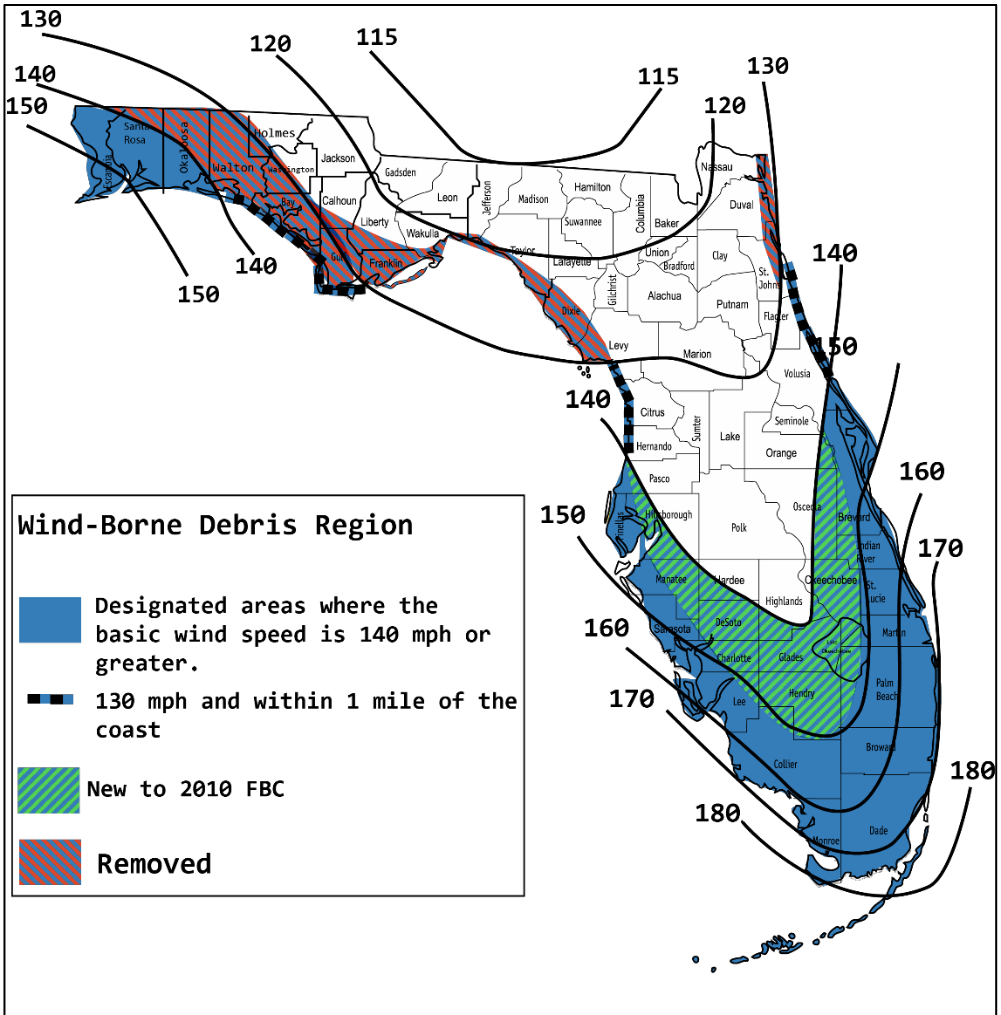


Figure 1609A Wind-Borne Debris Region, Category II and III Buildings and Structures except health care facilities

Figure 2- Design wind speeds in Florida for Category III buildings with surgical healthcare and Category IV buildings after the 2010 revision to the Florida Building Code[11].

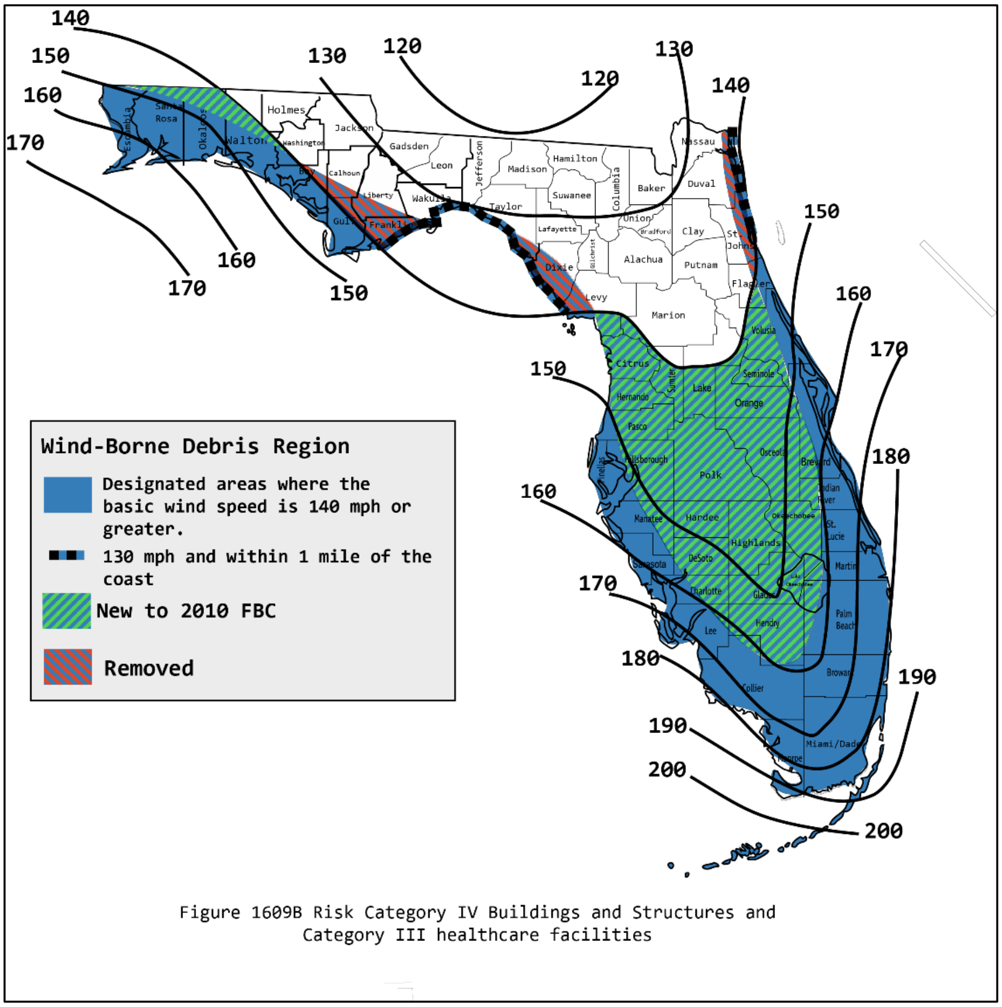
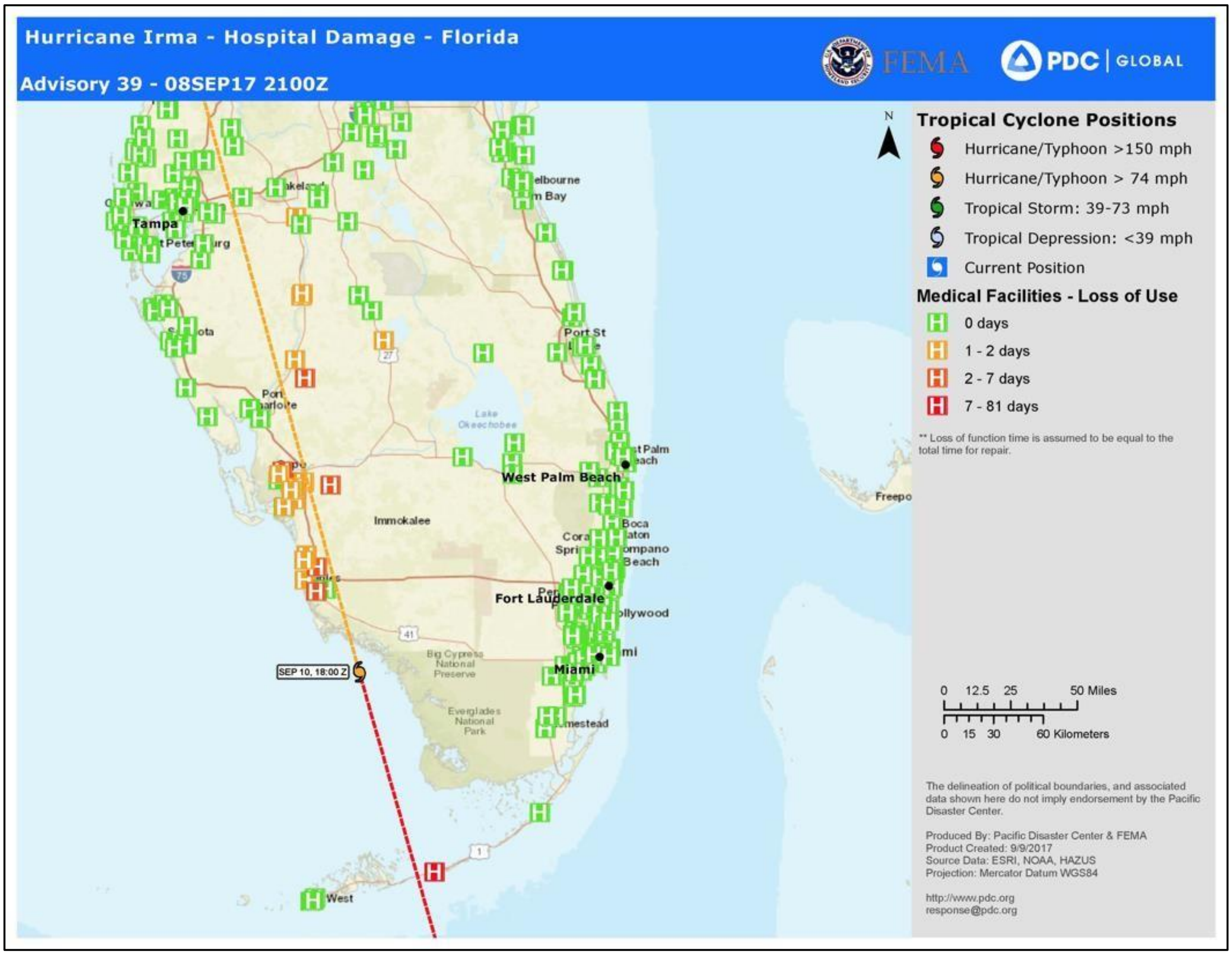


Figure 3: Loss of use time in days for medical facilities in the path of Hurricane Irma[15].



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