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Hurricane Loss Reduction

FOR

HOUSING IN FLORIDA:

EFFECT OF VEGETATION ON RESIDENTIAL BUILDING DAMAGE FROM HURRICANE ANDREW, AUGUST 1992

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Introduction

Objective

This study examined the relationship between location and density of nearby vegetation and extent of residential building damage evident from Hurricane Andrew. Vegetation can absorb and deflect winds away from structures. Conversely, vegetation can increase damage to structures if poorly located and uprooted or broken. Aerial photos, taken approximately 2 ½ weeks after Hurricane Andrew, were used to examine patterns of storm damage in residential neighborhoods in a qualitative visual assessment of the negative or positive effects of vegetation.

Background

Hurricane Andrew formed over the west coast of Africa as a tropical depression and turned into a tropical storm as it passed over the warm North Atlantic Ocean on 17 August 1992. Andrew was first classified as a Category 5 hurricane on August 23rd. Later that day, a second eyewall was formed concentrically around the original, but in the early morning of 24 August 1992, the pressure increased to 941 hPa and only the external eyewall was present. After Hurricane Andrew made landfall at Homestead, Florida, the pressure dropped to 922 hPa, the hurricane strengthened, and once again gained Category 5 strength (Willoughby and Black 1996; Landsea 2002).

Where Andrew's eyewall intersected the South Florida coast, several cells or vortices formed in the northern part of the eyewall (Landsea 2002). The interaction with land amplified the friction within the hurricane, which allowed the vortices to strengthen, and formed into cyclonic mesovortices on either side of the eyewall (Willoughby and Black 1996). These vortices contained fast moving winds with deep convection and caused the worst damage. Hurricane Andrew also contained swaths, which had winds within winds and followed the same path as the mesovortices. A swath is a zone of exceptional winds (50 to 175 mph) lasting from 5 to 15 minutes, and containing microbursts, strong winds that come straight down from above, and mini-swirls (Dorschner 1993). The worst damage from Hurricane Andrew was north of the eye, creating an asymmetric area of wreckage that is usually associated with tornadoes (see Map A-1 in Appendix A).

To assess the damage caused by Hurricane Andrew's winds, a house-to-house evaluation was required because of the spottiness and streaks of damage left behind. The levels of building damage can be directly associated with the quality of construction, as well as how the building is situated in relation to the oncoming winds. Most of the buildings in the areas with low levels of damage were built with straps wrapped around the trusses and rafters to hold the roofs on, and most of the buildings were concrete-block stucco with steel-reinforced concrete girders (Wakimoto and Black 1994). However, many other buildings were built with hurricane clips, which are weaker than the straps. The local nature of mesovortices, swaths, microbursts, and mini-swirls caused some structures to have light damage, while the building right next door would have severe damage.

It was found that buildings situated in a northwest to southeast diagonal direction had less damage because there the swaths only struck the ends of the buildings. Structures at the northwest corner of intersections were more vulnerable than the buildings on the southeast corners (Dorschner 1993). In addition, homes with garages facing the wind were the most vulnerable due to weakness in the garage door. The change of direction of the winds, flying debris, varying construction quality, vortices, and swaths all contributed to the wreckage patterns within highly damaged areas (Dorschner 1993; Wakimoto and Black 1994).

Methods

Selection of Study Areas

In a study published on December 20, 1992, investigators at the Miami Herald determined that damage patterns to homes were most influenced by location in a particular subdivision (Doig, Leen et al. 1992). This was a reflection of varying construction practices and lack of enforcement of the Miami-Dade County building code after about 1980. Between Kendall Drive and SW 184th Street, in a zone of moderate winds, the Herald found that 33% of inspected homes built after 1980 were uninhabitable, as opposed to 10% built prior to 1980. In view of the impact of residential home construction methods on damage, assessment of the role of vegetation would need to minimize these construction effects. Study areas were chosen in areas experiencing more moderate wind speeds and where the bulk of construction occurred prior to 1980. The majority of the subdivisions included in the study had low levels of uninhabitable houses based on the Miami Herald report. The exception was Bel Aire, a long established area that seemed to have a disproportionate severity of damage given its age.

Five areas were included in the analysis. A summary for those areas is shown in Table 1. A map of the study areas can be found in Appendix A (Map A-1). The areas are named after a large subdivision found there. Subdivisions were chosen as the focus of the study, since housing types and construction methods are more standardized than in custom built homes. Houses on larger lots were preferred because of more variety in landscaping. Data for percent Uninhabitable homes were taken from the Miami Herald study (Doig, Leen et al. 1992). All sections for a subdivision were taken together.

Processing of Aerial Photographs

Black and white aerial photographs were purchased from Pan American Surveys, Inc. of Miami, Florida. They were taken about 2 ½ weeks after Hurricane Andrew. The electronic “tiff” formatted images were scanned from the film negatives. However, because of cost considerations, the negatives were scanned at a lower resolution on a desktop scanner, rather than with a photogrammetric scanner. This process resulted in the loss of detail and contrast from the original negatives. In addition there was significant vignetting in the photographs, resulting in further loss of detail. Camera calibration and fiducial marks were not provided. In many cases, there is a reduced ability to see detailed features of roofs and nearby vegetation in the aerial photographs used for classification.

The aerial photographs were georeferenced using 1999 black and white ortho aerial photographs obtained from Miami-Dade County. The projection used in this study was transverse mercator, NAD83 datum, the state plane coordinate system, Florida FIPS 0901 in feet. After georeferencing, adjacent images were mosaicked where necessary to cover a study area. Radial distortion in the images was not corrected.

Table 1: Location and principle subdivisions for five study areas. The data for percent uninhabitable homes are from the Miami Herald study (Doig, Leen et al. 1992).

Area	Location	Representative Subdivisions	%Uninhabit.
BelAire	SW 190 St & SW 90 Ave	Bel Aire	74, 77
		Holiday House	NA
		Pine Tree Manor	84
		Cutler Ridge Manor Estates	85
Coral Reef	SW 152 St & US 1	Coral Reef Estates	25, 50
		Fairway Park	0, 11
		Fairway Estates	0
		Lakeshore	0
		Southwood	3
		Palmetto Country Club Estates	0, 0, 6, 3, 5
		Peacock Place	NA
Redland2	SW 272 St & SW 167 Ave	The Redlands	2
		Universal Estates	69, 77
		Melody Manor	0
		Heritage Trail	NA
Pine Shores	SW 104 St & SW 97 Ave	Pine Acres	0
		Pine Shore	4, 2, 0
		Oakland Acres	0
		Pine Needle Estates	NA
Lindgren	SW 104 St & SW 127 Ave	Calusa Club Estates	NA
		The Crossings	NA
		Lindgren	NA

Detection of Building Damage

The study uses a qualitative visual analysis to assess building damage. Single family houses were placed in three building damage categories based on visual inspection of roof damage using the aerial photographs. Because the photos were taken 2 ½ weeks after the storm, repairs were already underway on many homes, and damage assessment was inferred from the repairs being made. Table 2 gives a description of the three damage categories. Aluminum framed patio screening was not considered part of the house. Additions with a permanent roof were considered part of the house.

Figure 2 shows examples of damaged shingle roofs. Both of these houses would be rated "severe" due to the loss of roof deck and collapse of wall shown circled. Houses with either black or white shingles were often graded "Unknown" because of the inability to see details in the photos. In addition bare roof decking also appeared bright white, causing these houses to be graded as "Unknown". Sometimes roof trusses are left exposed as architectural elements over patios or courtyards. Presence of debris, placement and shape of the openings were used to distinguish these cases from a case of severe roof damage.

Table 2: Description of building damage categories based on examination of roof features in black and white aerial photographs.

Mild damage	Little visible roof damage – limited loss of shingles or tiles
	Damage to metal framed screened patios
	Lack of building debris around house
Moderate damage	Significant loss of roof shingles and/or underlying materials
	Tiles or shingles scattered on ground
	Roof decking may be visible
	Roof decking is intact
	Roof is covered with tarps
	New roof construction including roofing felt, flashing, shingles or tiles
Severe damage	Loss of roof decking – trusses are visible
	Loss of roof trusses
	Collapse of walls
	Building debris scattered around house
Tree	Tree(s) are lying on the roof obscuring damage underneath
Unknown	Roof could not be assigned to a class

Figure 2: Example of severely damaged shingled roofs.

Source: www.photolib.noaa.gov

Tile roofs can have flat or barrel tiles. Like the shingles, houses with white tiles were often graded "Unknown". In some cases, tiles could be seen littering the ground in the downwind direction. Figure 3 shows examples of tile roofs. Notice the tiles scattered on the ground and the built up layers of roofing material on the decking.

Figure 3: Example of damaged tiled roofs with broken tiles scattered on the ground.

Source: www.photolib.noaa.gov

A third roof type seen is a flat built up roof. Since many of these roofs are white or light gray, they were probably disproportionately graded "Unknown" because details were not visible.

Additional examples of roofs from the study are shown in Figures 4 - 9. The radial distortion in the aerial photos causes the houses to "lean" away from the center of the photo. Therefore one or two walls of the house may be visible depending on where in the photo the house is located.

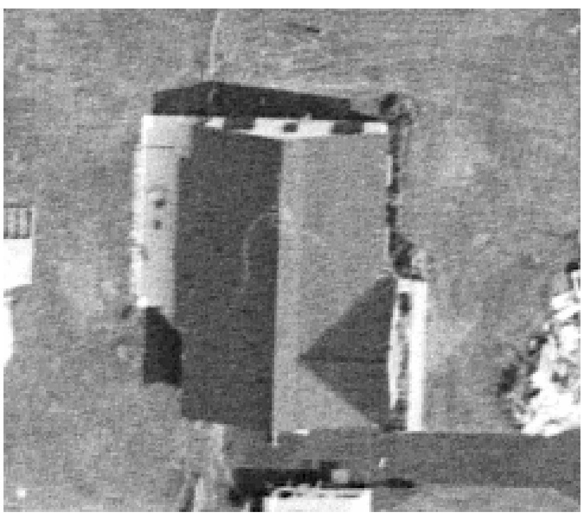
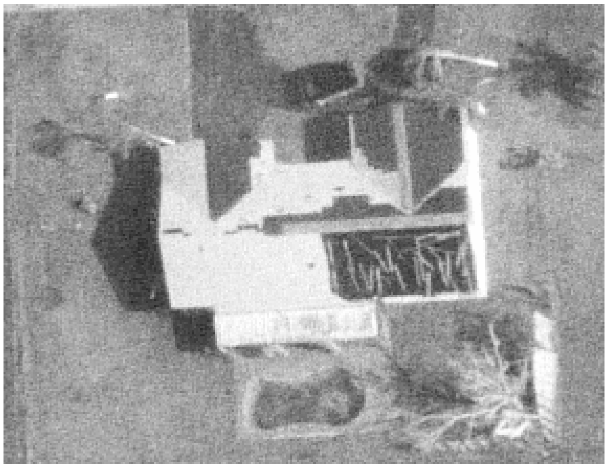


Figure 4: This house is classified as "mild". There isn't visible roof damage and the edges of the roof are sharp.



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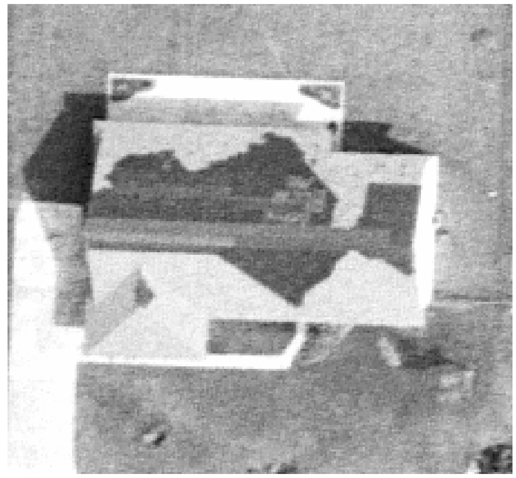

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Figure 5: These houses are classified as “moderate”. Both show peeling of the layers of the roof. The owner of the house on the left has nailed strapping to hold down a tarp or tarpaper. The house on the right shows evidence of temporary patching as well.

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Figure 6: This house is classified as “moderate” as well. The bright edge along with the striping running parallel to the roof ridges suggests that new roofing felt has been applied to the whole roof with metal edge flashing. This level of repair would suggest a “moderate” rating.

Figure 7: These houses are classified as “severe”. In all cases there is loss of roof decking, and trusses are clearly visible. Debris litters the ground. The house to the left shows a catastrophic loss of the entire roof, which is lying on the ground in front of it.

Figure 8: This house is classified as “tree” because a fallen tree is obscuring visibility of the roof.


©Pan American Surveys, Inc. 1992

Figure 9: This house is graded as “unknown”. The high reflectance obscures any determination of roof detail.

Patterns of Yard Vegetation

It was difficult to analyze the state of trees located on the property parcel. Figure 10 below shows a parcel with abundant woody vegetation.

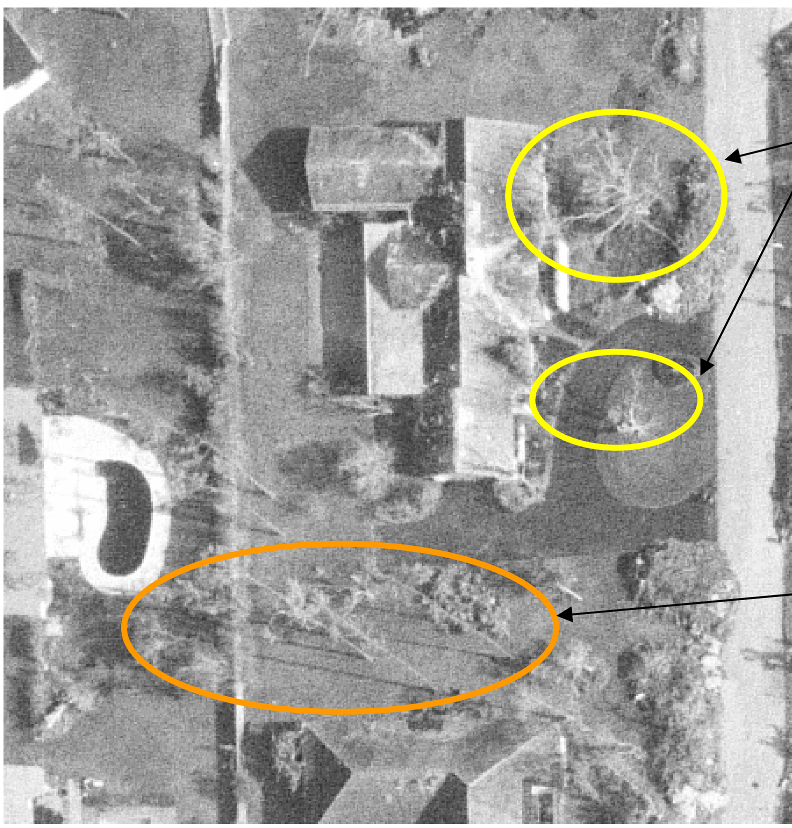
©Pan American Surveys, Inc. 1992

Figure 10:

These broad-leaved trees have remained standing but all the leaves were stripped from the branches. Here the tree can be seen. Sometimes only the shadow reveals the presence of trees. These trees may be been much larger, but the outer canopy branches were all broken.

These long thin single boles belong to trees such as palms or pines. Again the shadows aid in their detection.

As shown in Figure 11, some trees can be seen fallen down flat with a tip-up mound containing the root ball. In many cases, homeowners have cleaned up the fallen vegetation and piled it at the curb in front of their homes.


©Pan American Surveys, Inc. 1992

Figure 11:

This is an example of a fallen tree with roots exposed.

This tree is still upright but with most of the leaf canopy missing.

The trees located on each property parcel were placed into three categories.

No Trees	There is no evidence of standing trees or piles of debris at the curb. Lower vegetation such as hedges are not included as trees.
Occasional Tree	The parcel has a few scattered trees. Mature trees do not threaten the structure of the house.
Trees Present	There is a well-defined canopy of mature trees throughout the parcel. There are single large mature trees that can threaten the structure of the house.

Because of the small lot sizes in the Lindgren area, the "occasional tree" category was not used. Any substantial tree on the lot could threaten the structure of the house. The remaining attribute recorded for each house was for location on a corner of two streets. Visual assessments were done using ArcGIS (ESRI). The georeferenced aerial photographs were displayed in a map, and a point shapefile was created. Roof damage assessment, presence of trees on the parcel and location on a corner were entered into the attribute table for each house evaluated. Most properties were inspected by three independent operators, and the final assessment was determined by the majority. In the event all three operators disagreed, the property was classified by the most experienced reviewer.

<u>Neighborhood Vegetation Characteristics</u>

A polygon shapefile was created in ArcGIS to classify vegetation characteristics of the neighborhood. Three classes of vegetation were described.

Suburban	The houses are arranged on lots and surrounded by other houses.
Open	The houses are adjacent to an open area such as school ground, park, canal, lake, golf course, potted plant nursery, agricultural field or cleared open land.
Vegetated	The houses are adjacent to a natural area, uncleared land, mature grove Houses located in forested rural areas.

Statistical Methods

Damage to houses was classified into three levels – mild, moderate and severe based on the criteria described above. The following associations were assessed:

1) Is the degree of damage associated with location within a particular subdivision?
The Miami Herald (Doig, Leen et al. 1992) found a strong association between building construction and degree of storm damage.

2) Is the presence or absence of trees on the property related to the degree of damage?
Large trees placed close to structures may be more likely to fall on the structure in a storm.

3) Is the degree of damage associated with the location of the property adjacent to an open unvegetated area, a wooded area or within a subdivision?
Open unvegetated areas may be more vulnerable to the direct effects of winds; whereas adjacent wooded areas can be a windbreak to deflect winds away from structures.

4) Is the degree of damage associated with a property location on a street corner?
Houses located at the intersections of streets may be more vulnerable to wind than houses located within a cluster of other houses.

The data in this study consists of count data representing the number of houses arranged in a two way contingency table for damage severity and a second variable of interest. The paired comparisons compiled were:

Damage severity and subdivision (question 1).
Damage severity and presence of trees on property (question 2)
Damage severity and characteristics of neighborhood vegetation (question 3)
Damage severity and location of property on a street corner (question 4)

The statistical test used in this analysis is the chi square test of independence (Daniel 1990; SAS Institute 2005). If damage severity and the presence of trees on the property are associated, then knowing that trees are present would allow us to predict the degree of damage of the house. The observed counts in a contingency table are the joint occurrence of each category. The observed counts are compared to the counts expected if there were no association. A sample of this analysis is shown in Table 3.

Table 3: Sample contingency table analysis

Sample contingency table

1st category (trees)	2nd category (damage) Mild	Moderate	Severe	Row Total
No Trees	n_{11}	n_{12}	n_{13}	$n_{1.}$
Occasional Trees	n_{21}	n_{22}	n_{23}	$n_{2.}$
Trees	n_{31}	n_{32}	n_{33}	$n_{3.}$
Column Total	$n_{.1}$	$n_{.2}$	$n_{.3}$	$n_{..}$

The hypothesis tested is

H_0: The two criteria (e.g. Damage severity and presence of trees) are independent (not associated)
H_A: The two criteria are not independent

If H_0 is true then the expected value (e) for events meeting both criteria for the circled cell is $e_{11} = ((n_{.1})*(n_{1.}))/(n_{..})$. Expected values can be calculated similarly for each cell. This expected value is compared to the actual observation for each cell. The test statistic follows the χ^2 distribution

$$\chi^2 = \sum\sum\left[\frac{(\text{Obs-Exp})^2}{\text{Exp}}\right] \qquad \text{(Equation 1)}$$

The decision rule is that H_0 is rejected at $\alpha=0.05$ if the calc $\chi^2 > \chi^2(1-\alpha)$ for (r-1)(c-1) df. If H_0 is rejected, then the two categories are not independent. In other words, they are associated. In this example, the presence of trees on the property does provide information about the severity of damage to the house. To determine the strength of the association Cramer's V statistic was used. This statistic is independent of table size. Values range between 0 (no association) and 1 (maximum association). A value of 0.1 can be used as a guideline for a meaningful association. Cramer's V is calculated as

$V = \sqrt{(\chi^2/nm)}$ where n = sample size and m is the min(r-1), (c-1) (Equation 2)

Statistical analyses were done using SAS 9.1.3 (SAS Institute, Cary, NC).

Results and Discussion

A total of 4410 houses in 5 study areas were evaluated. A summary is shown in Table 4. Detailed maps for each study area are included in Appendix A, Nos. 2 - 10. These maps show houses evaluated marked in purple with severely damaged houses marked in orange.

Table 4: Summary of houses analyzed for damage severity

Area		Total	Damage Severity			Tree	Unknown	Corner	
			Mild	Moderate	Severe			Yes	No
Bel Aire		1025	72	750	61	19	123	174	851
	%	100.0	7.0	73.2	6.0	1.9	12.0	17.0	83.0
Coral Reef		1035	123	676	68	26	142	252	783
	%	100.0	11.9	65.3	6.6	2.5	13.7	24.3	75.7
Lindgren		1031	167	635	43	16	170	218	813
	%	100.0	16.2	61.6	4.2	1.6	16.5	21.1	78.9
Pine Shore		951	252	537	20	33	109	234	717
	%	100.0	26.5	56.5	2.1	3.5	11.5	24.6	75.4
Redland 2		368	50	258	33	3	24	88	280
	%	100.0	13.6	70.1	9.0	0.8	6.5	23.9	76.1

The majority of houses in all areas were moderately damaged. The Redland 2 area (Map A-7) is rural and the furthest south. The eye of Hurricane Andrew passed over this area. It had the highest percentage of severely damaged homes. Pine Shore and Lindgren (Maps A-8,9,10) are both located around SW 104th Street, they are the furthest north. Pine Shore had the lowest percentage of severely damaged homes and the highest percentage of the mild class.

The percent of homes classified as unknown is a reflection of the difficulty of assessment with the aerial photos. While some of the photos were clear, many lacked focus and contrast. Based on the absence of building debris in the yards, it is likely that the unknown class represents intact roofs covered with light colored shingles, tile or other coatings. Hence the mild class may be under-represented in the final tabulation. In more heavily damaged areas, such as Bel Aire, roofs with exposed wood deck may also be placed in the unknown category resulting in under-representation of moderately damaged houses. A consistently low percentage of houses had trees resting on the roofs. However, an important factor is that the photos were taken 2 ½ weeks after Hurricane Andrew. Although the damage was extensive and many areas were lacking power, many houses showed evidence of cleanup and repair.

<u>Association of Damage Severity with Subdivision Location</u>

Homes in the study areas were located in subdivisions or as section land where homes were built individually. Because the numbers of homes in the subdivisions were relatively small, and the frequency of severely damaged homes is under 10%, the use of the chi square test of independence is limited. The expected frequency for any cell in the contingency table must be greater than 5 (SAS Institute 2005) or 10 (Daniel 1990) to get a valid analysis. The only area that could be analyzed in this way is Bel Aire. The output from SAS is shown in Table 5.

Contingency table analysis requires that each house fit into only one classification. Hence only homes in the mild, moderate and severe classifications were used. Homes were placed in the tree and unknown classifications due to lack of visibility of roof features. These homes would otherwise fall into the mild, moderate or severe classes. Like other parametric statistical tests, the chi square test for independence is sensitive to sampling bias.

Table 5: Contingency table analysis for Bel Aire study area.

Table of Subdiv by FinalClass

Subdiv(Subdiv) FinalClass(FinalClass)

Frequency Expected Deviation Cell Chi-Square	mild	moderate	severe	Total
Belaire	55 48.027 6.9728 1.0123	508 500.28 7.7169 0.119	26 40.69 -14.69 5.3032	589
Cutler Ridge Manor Est	2 8.0725 -6.072 4.568	73 84.088 -11.09 1.4622	24 6.8392 17.161 43.06	99
Holiday House 1	4 3.0985 0.9015 0.2623	32 32.276 -0.276 0.0024	2 2.6251 -0.625 0.1489	38
Pine Tree Manor	11 12.802 -1.802 0.2536	137 133.35 3.6478 0.0998	9 10.846 -1.846 0.3142	157
Total	72	750	61	883

Statistics for Table of Subdiv by FinalClass

Statistic	DF	Value	Prob
Chi-Square	6	56.6056	<.0001
Cramer's V		0.1790	

Sample Size = 883

With only 38 houses, the expected values for the Holiday House subdivision were too low to be considered in the analysis. The χ^2 value with 6 degrees of freedom (df) is 56 and $p < .001$. The largest contributor to the χ^2 value is the association between the subdivision Cutler Ridge Manor Estates and severely damaged homes. With an expected value of 6.8 severely damaged homes, the observed value of 24 severely damaged homes is significantly greater than expected. The value of Cramer's V is 0.179. On a scale of 0 to 1, the association is still small however. See Appendix A Map A-2 for a map of the Bel Aire study area. The map shows that the severely damaged homes appear to be clustered in section Bel Aire 1 as well. However, all the Bel Aire sections were analyzed together in order to get sufficient numbers. Other factors may also be involved in the clustering of severely damaged homes, such as wind exposure and local fluctuations in the severity of the storm (see background). There were many cases of adjoining homes being destroyed while others nearby remained nearly untouched.

Association of Damage Severity with the Presence of Trees

Trees were evaluated for each property. The three classes were no visible trees, an occasional small tree and abundant large trees or large single trees that could threaten the structure of the house. This assessment was sensitive to the 2 ½ week lag because clearing the downed trees obscured the landscape at the time of the storm. A summary of the analysis is in Tables 6-8. Tests with p values < 0.05 are shown in detail for Coral Reef and Bel Aire.

Table 6: Summary of statistical data for presence of trees analysis

Area	p val for χ^2	Cramer's V
Coral Reef	0.0392	0.0763
Bel Aire	0.007	0.0893
Pine Shore	0.145	NA
Lindgren	0.4563	NA
Redland2	0.209	NA

Table 7: SAS Report for Coral Reef Area

Table of trees by FinalClass

trees(trees) FinalClass(FinalClass)

Frequency Expected Deviation Cell Chi-Square	mild	moderate	severe	Total
no	24 18.884 5.1156 1.3858	96 105.5 -9.503 0.8559	15 10.613 4.3873 1.8137	135
occ	37 49.239 -12.24 3.0423	292 275.09 16.911 1.0396	23 27.672 -4.672 0.7887	352
yes	60 52.876 7.1237 0.9597	288 295.41 -7.408 0.1858	30 29.716 0.2844 0.0027	378
Total	121	676	68	865

Statistics for Table of trees by FinalClass

Statistic	DF	Value	Prob
Chi-Square	4	10.0742	0.0392
Cramer's V		0.0763	

Sample Size = 865

In the Coral Reef Area, the results show a weakly significant p value for the χ^2 and Cramer's V shows a weak association between trees and severity of building damage. There is not a clear trend in the data showing over or under-representation in a particular class. For further details see maps in Appendix A (No. 3 – 6).

Table 8: SAS Report for Bel Aire Area

Table of trees by FinalClass

trees(trees) FinalClass(FinalClass)

Frequency / Expected / Deviation / Cell Chi-Square	mild	moderate	severe	Total
no	23 18.51 4.4904 1.0893	195 192.81 2.1914 0.0249	9 15.682 -6.682 2.847	227
occ	20 23.891 -3.891 0.6338	259 248.87 10.133 0.4125	14 20.241 -6.241 1.9244	293
yes	29 29.599 -0.599 0.0121	296 308.32 -12.32 0.4926	38 25.077 12.923 6.6596	363
Total	72	750	61	883

Statistics for Table of trees by FinalClass

Statistic	DF	Value	Prob
Chi-Square	4	14.0964	0.0070
Cramer's V		0.0893	

Sample Size = 883

The p value for χ^2 is highly significant, but again Cramer's V is showing that the strength of the association of these two variables is marginal. This was also the area that showed a clustering of the severe damage class (see Appendix A-2 for Bel Aire Study Area map) in two areas (Bel Aire 1 and Cutler Ridge Manor Estates).

Three of five study areas did not show a significant association between damage to the houses and the density of trees on the properties. While there were cases of trees fallen on houses, the frequency did not exceed 3.5% of all houses examined. The two cases where there may be an association of building damage with trees, that association is weak using the Cramer's V test. Presence of trees on the property does not seem to pose an increased degree of building damage.

Association of Damage Severity with Neighboring Vegetation

Nearby vegetation may have an impact on building damage due to open spaces that funnel the wind towards a building or a stand of trees that can block or divert the wind. For each study area, polygons were drawn delimiting neighborhoods adjacent to open areas, adjacent to wooded or vegetated areas or contained within areas of similar housing. Using the spatial join feature in ArcGIS, each point representing a house was included in one of these polygons. The chi square test for independence tested the relationship between building damage severity and inclusion in a particular polygon. The results are summarized in Table 9.

Table 9: Summary of statistical data for neighboring vegetation analysis

Area	p val for χ^2	Cramer's V	#Open	#Vegetated	#Suburb
Coral Reef	<0.001	0.1835	288	164	411
Pine Shore	0.001	0.1478	245	0	564
Lindgren	0.0025	0.1193	302	0	542
Bel Aire	0.0798	NA	295	0	588
Redland 2	0.2099	NA	98	32	211

Three of the five areas show a significant association between building damage severity and neighboring vegetation; however, it was not possible to draw polygons for each type for all areas. Wooded areas such as groves or natural pinelands or hammocks are relatively rare in Miami Dade County. The Coral Reef area is perhaps the best area to examine (see Appendix A for maps) since there were both open areas and vegetated areas. The detailed analysis for Coral Reef and Pine Shore is shown in Tables 10 and 11 and maps in Appendix A (No. 3 – 6, 8).

Table 10: Coral Reef Area

VegClass(VegClass)   FinalClass(FinalClass)

Frequency Expected Deviation Cell Chi-Square	mild	moderate	severe	Total
open	56 40.38 15.62 6.0421	205 224.93 -19.93 1.7654	27 22.693 4.3071 0.8175	288
suburban	25 57.626 -32.63 18.472	365 320.99 44.01 6.0342	21 32.385 -11.38 4.0022	411
vegetated	40 22.994 17.006 12.577	104 128.08 -24.08 4.5284	20 12.922 7.0776 3.8765	164
Total	121	674	68	863

Frequency Missing = 2

Statistics for Table of VegClass by FinalClass

Statistic	DF	Value	Prob
Chi-Square	4	58.1148	<.0001
Cramer's V		0.1835	

Effective Sample Size = 863

Table 11: Pine Shore Area

Table of VegClass by FinalClass

VegClass(VegClass) FinalClass(FinalClass)

Frequency Expected Deviation Cell Chi-Square	mild	moderate	severe	Total
open	83 76.316 6.6836 0.5853	148 162.63 -14.63 1.3155	14 6.0569 7.9431 10.417	245
suburban	169 175.68 -6.684 0.2543	389 374.37 14.627 0.5715	6 13.943 -7.943 4.5251	564
Total	252	537	20	809

Statistics for Table of VegClass by FinalClass

Statistic	DF	Value	Prob
Chi-Square	2	17.6685	0.0001
Cramer's V		0.1478	

Sample Size = 809

For the Coral Reef area, there does not seem to be a definite trend in the data. In the Pine Shore area, severely damaged houses are over-represented in open areas and under-represented in suburban areas in contrast to the Coral Reef area. Many of the homes there are on large vegetated lots, and many are potted plant nurseries. It was difficult to draw nonoverlapping polygons that included houses adjacent to strictly open or vegetated areas. Many homes were adjacent to land having mixed uses – both grove and agriculture for example.

Association of Damage Severity with Location on a Street Corner

Houses located on street corners are most exposed to winds channeling along the intersecting streets. This comparison looks for an association of building damage with location on a corner. The results are summarized in Table 12.

Table 12: Summary of statistical data for street corner analysis

Area	p val for χ^2	Cramer's V	#Corner	#Otherwise
Coral Reef	0.2343	NS	252	783
Pine Shore	0.1081	NS	234	717
Lindgren	0.3533	NS	218	813
Bel Aire	0.9694	NS	174	851
Redland 2	0.7670	NS	88	280

There did not appear to be any association between building damage and location on a street corner.

Conclusions

Investigative work has found that both the local extreme events seen in Hurricane Andrew and variable home construction methods significantly contributed to the extensive damage to residential property. As such, perhaps this storm was too catastrophic to be able to detect relatively modest effects of vegetation in this study. Anecdotal evidence suggests that proper vegetation can offer protection to houses; conversely the wrong trees improperly placed can add to the damage.

This study relied on aerial photos taken 2 ½ weeks after the storm. Although this does not seem like a long time for a storm of this magnitude, people were already cleaning away tree debris and making substantial repairs to secure their houses and prevent further deterioration. In many cases, details of roof damage were obscured, and standing trees, stripped of all their leaf canopy were difficult to see.

The analysis showed a low percentage of trees that had fallen on roofs (<3.5%). In the Bel Aire area, there seemed to be an association between properties containing large tree canopy and severe building damage, but this association was weak and not seen elsewhere. Bel Aire was also the area with a high percentage of uninhabitable houses (>70%). Some of the houses directly along the canal were affected by storm surge flooding, and this may have contributed to the high degree of uninhabitable homes.

In the Pine Shore community there appeared to be a weak association of open areas lacking trees and severe building damage, but this association was not seen in other areas. Locations on street corners did not seem to be associated with severity of building damage. In general, this study did not reveal clear patterns for the association of vegetation characteristics with residential building damage.

Future Assessments

It is reasonable to expect that vegetation can absorb and deflect hurricane winds if properly planted and maintained. As a category 5 hurricane, Hurricane Andrew presented the most severe conditions making it unlikely that vegetation could mitigate the force of the winds. Future studies for category 1 or 2 hurricanes may produce more clear trends. Other recommendations for additional studies are as follows:

- High resolution photogrammetrically scanned color photographs taken within a few days of the hurricanes

- Ground surveys of houses during the same period as the photographs to correlate features in the photographs with actual damage on the ground.

- Access to subdivision plats, approved plans and inspection reports so that effects of construction methods can be factored out of the study.

- Meteorological assessment of hurricane winds so that local weather conditions can be determined for study areas.

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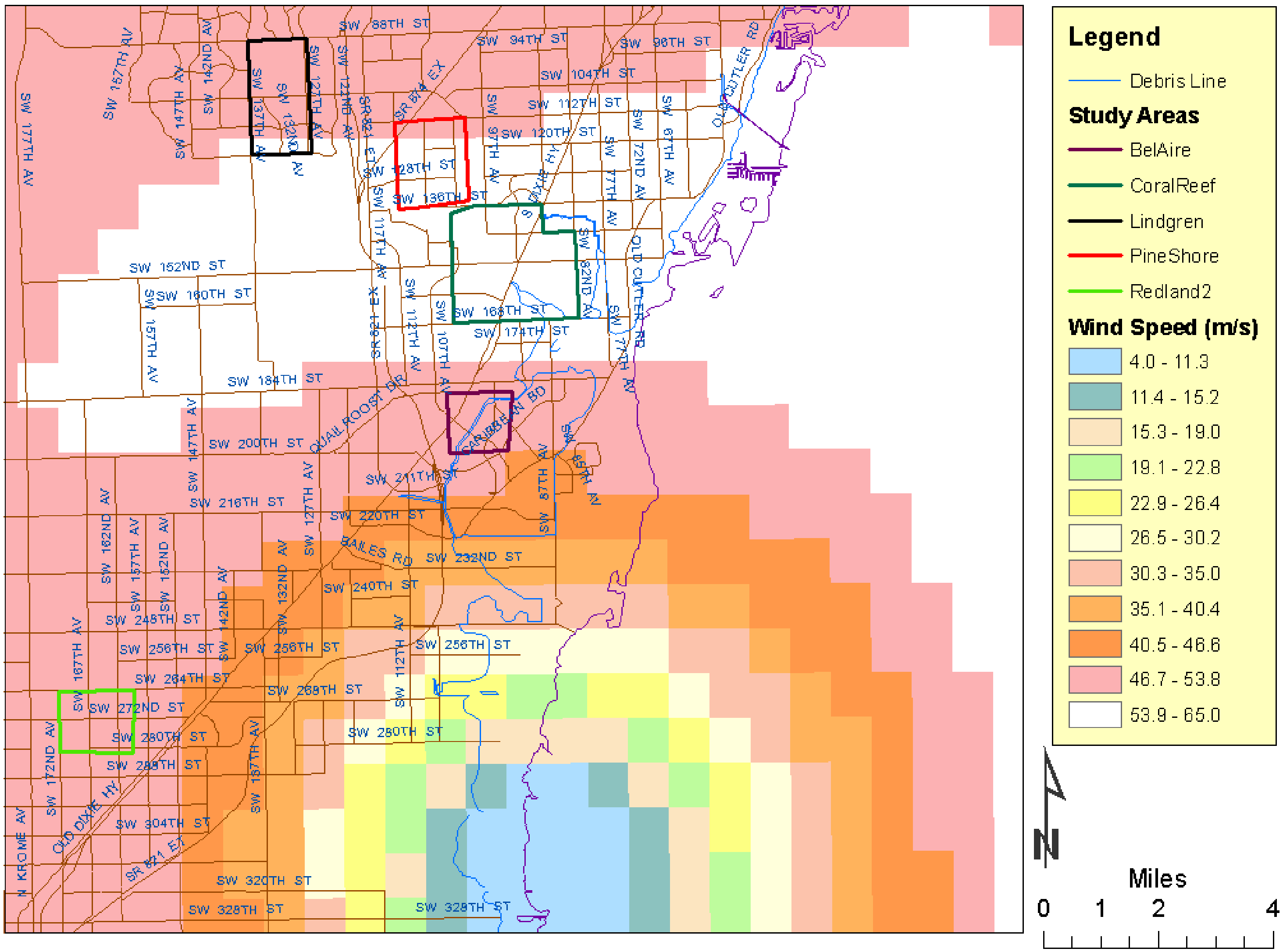
Appendix A: Maps of Study Area

1. Overview Map of Study Areas and Hurricane Andrew Windfield
2. Bel Aire Study Area
3. Coral Reef Study Area, NW Section
4. Coral Reef Study Area, NE Section
5. Coral Reef Study Area, SW Section
6. Coral Reef Study Area, SE Section
7. Redland 2 Study Area
8. Pine Shore Study Area
9. Lindgren Study Area, North Section
10. Lindgren Study Area, South Section

Map A-1

Study Areas for Hurricane Andrew Vegetation Study

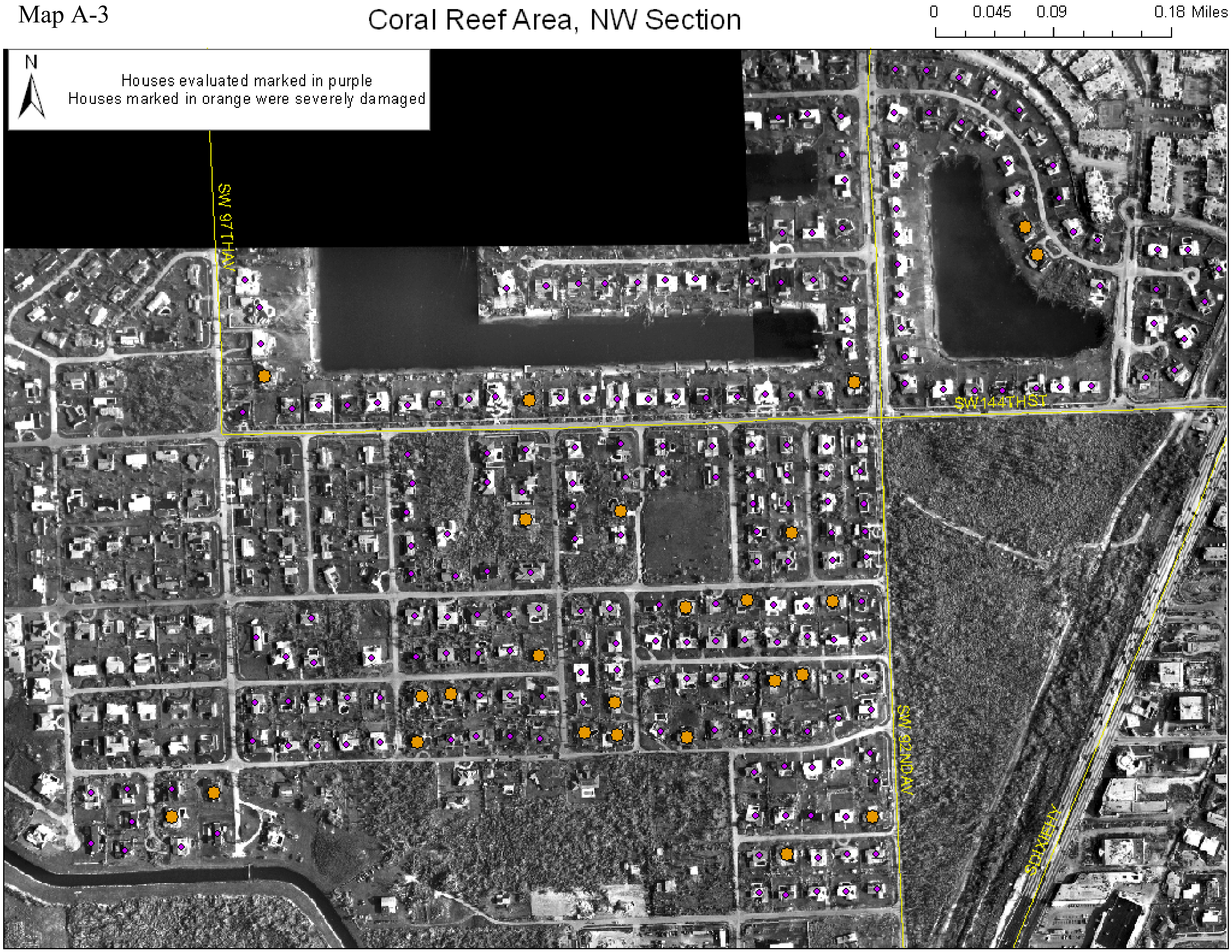


Map A-2

Hurricane Damage Bel Aire Area

Map A-3

Coral Reef Area, NW Section



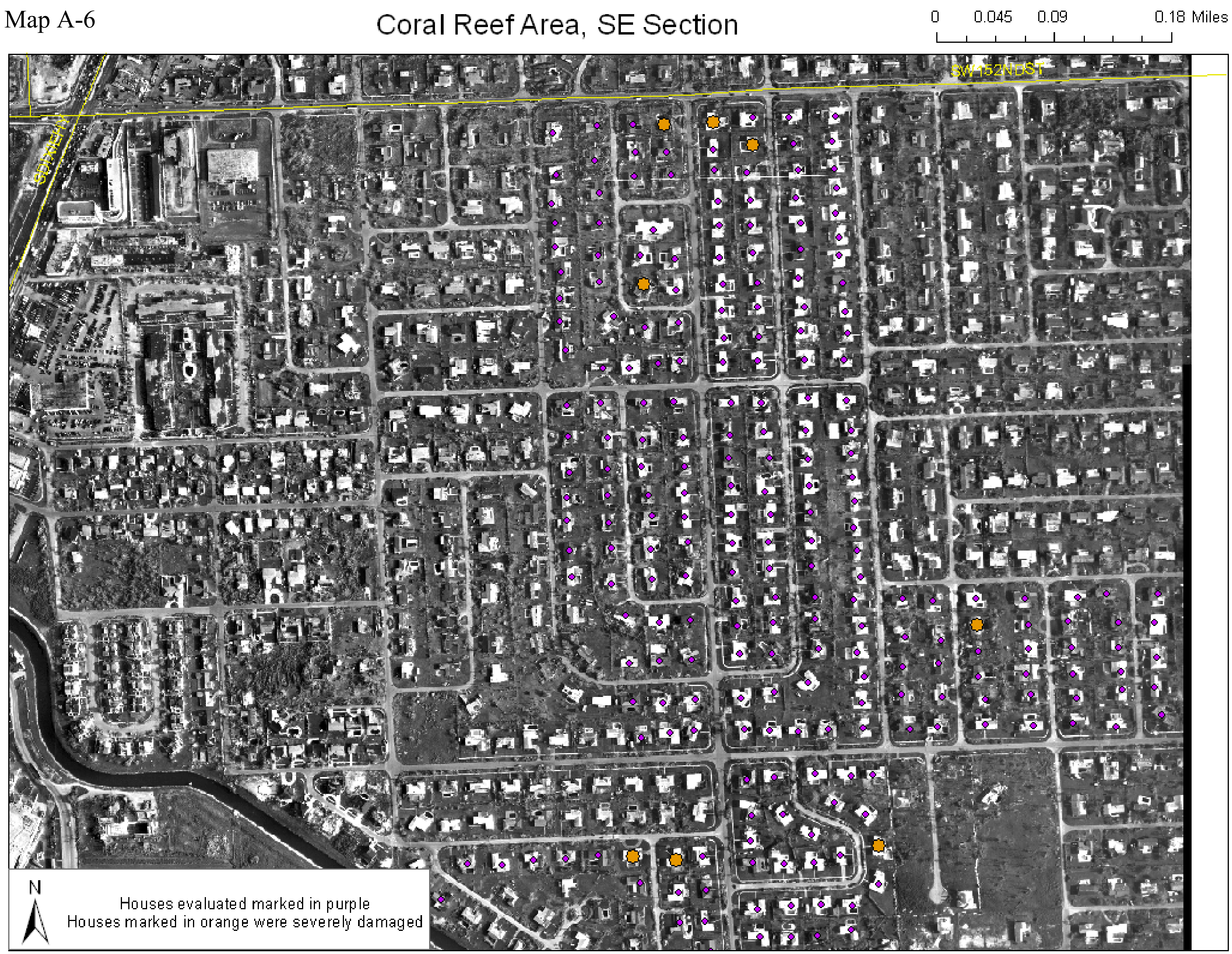
Map A-4

Coral Reef Area, NE Section

Map A-5

Coral Reef Area, SW Section

Map A-6



Coral Reef Area, SE Section
0 0.045 0.09 0.18 Miles
SW 152ND ST
N
Houses evaluated marked in purple
Houses marked in orange were severely damaged

N

Redland 2 Study Area

Map A-7

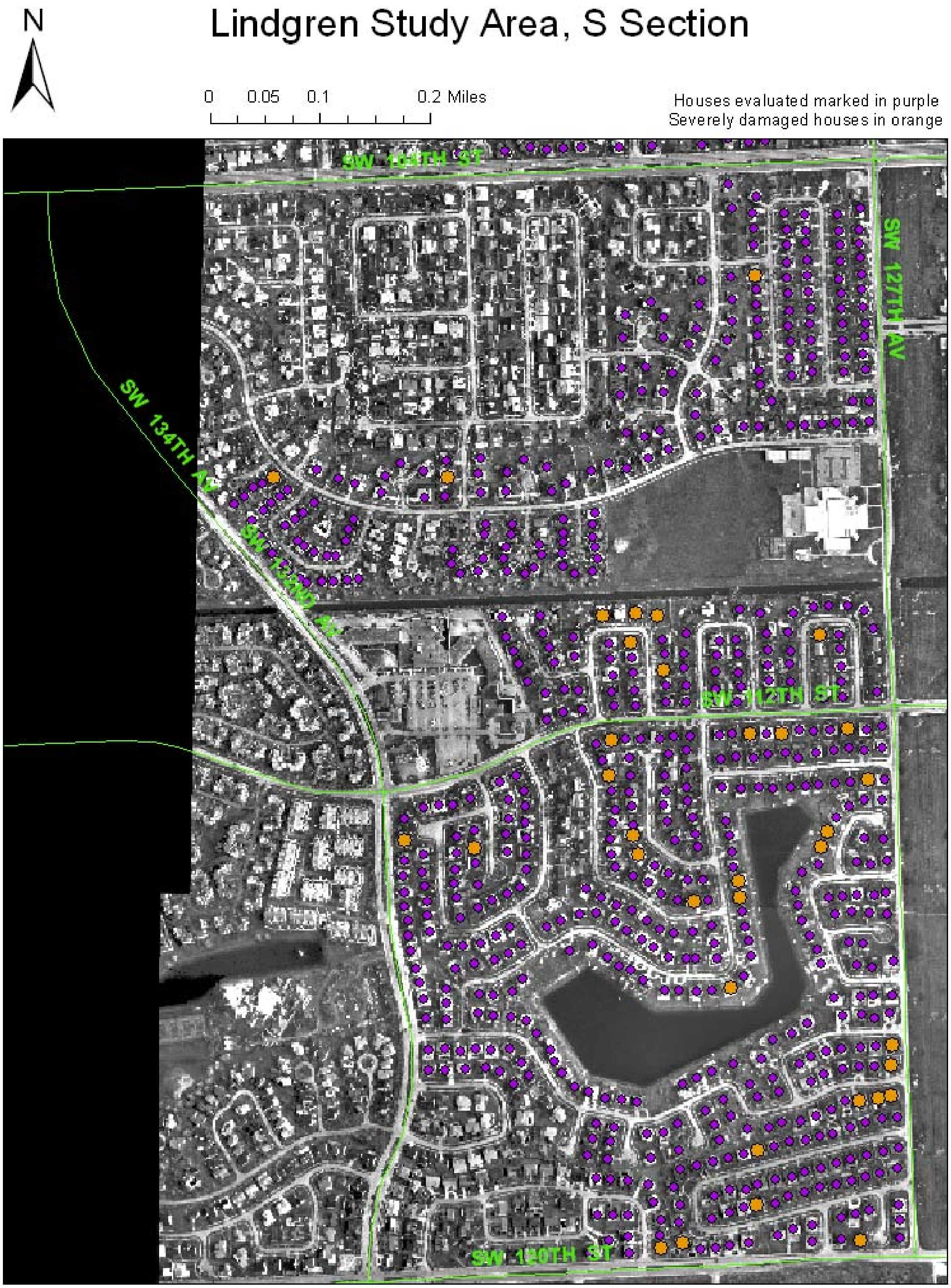
Map A-8


N
Pine Shore Study Area
0 0.045 0.09 0.18 Miles
Houses evaluated marked in purple
Severely damaged houses marked in orange
SW 120TH ST
SW 128TH ST
SW 102ND AV
SW 107TH AV

Map A-9

N
Lindgren Study Area, N Section
0 0.05 0.1 0.2 Miles
Houses evaluated marked in purple
Severely damaged houses in orange
SW 88TH ST
SW 127TH AV
SW 104TH ST

Map A-10


N
Lindgren Study Area, S Section
0 0.05 0.1 0.2 Miles
Houses evaluated marked in purple
Severely damaged houses in orange
SW 104TH ST
SW 127TH AV
SW 134TH AV
SW 132ND AV
SW 112TH ST
SW 120TH ST